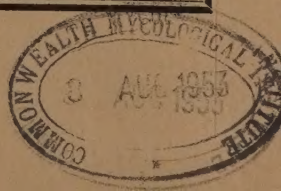
REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1952



Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT

for

1952

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The Commonwealth Bureau of Soil Science

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The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them, and by rendering any technical assistance possible when they are in this country. A bi-monthly abstact journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers, and the culture of field crops throughout the world is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly 60 years. Lawes died in 1900 and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943 when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000 the income of which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent. of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room, and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department.

In 1946, Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research and Advisory Departments.

In 1947, the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

A large new South Wing was completed in 1940, and the old chemical laboratories were reconstructed. These extensions and reconstructions have provided excellent accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition a fine range of pot-culture houses was built. A new

laboratory has also been built and equipped for workers from the Imperial College of Science and Technology.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930-32 and equipped for electric light and power. Further additions were made in 1939-40, and the electricity supply has now been extended to these newer buildings.

A further range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced, and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but the Station gains considerably by this closer association with the Universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934, the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted Estate were completed. The Rothamsted Trustees now own the site of the laboratories, the experimental and ordinary farm fields, Knot Wood, the Manor House and grounds, the farm manager's house, and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers, and from oversea sources.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually spreading out to the Commonwealth and other countries. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

The Station offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and Societies, was rapid, until it now contains:

	(Approximately)
Periodicals .. .. (Current, 1,100)	2,500
Books, 1841-	10,000
Books, 1471-1840 .. .. .. (including 14 incunabula)	3,500
Bound volumes of pamphlets ..	400
MSS.	55
Maps	300
Prints	100

—in all about 17,000 items, comprising some 38,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471-1840), which is kept separate from the rest, includes 14 incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture—produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry* by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948 when Lord Northbrook presented his Father's collection of prints to the Station.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books (Rothamsted, 1926; second edition, 1940; Supplement, 1949). A printed catalogue of periodicals is being prepared.

INTRODUCTION

By The Director

By the death of Professor F. T. Brooks on 11th March, 1952, the Lawes Trust Committee lost a valued member who, for many years, was intimately connected with Rothamsted. He was appointed to the Committee as a representative of the Royal Society in 1937 and from 1946 until his death was Treasurer. Professor Brooks gave much time and thought to the work of the Station and took a very active interest in the members of the staff.

It is with deep regret that we also record the death of Dr. J. Henderson-Smith, which occurred on 26th November, 1952. He was appointed to the newly-formed Mycology Department in 1919 and became head in 1933 when its name was changed to the Plant Pathology Department; he occupied this position until he retired in 1940.

During the year, Dr. T. Goodey retired from the headship of the Nematology Department but is continuing his work at Rothamsted. He has been succeeded as head of the department by Dr. B. G. Peters. Dr. C. Potter visited East Africa for the Colonial Office at the invitation of the Kenya and Tanganyika Pyrethrum Boards to advise on the problems of the pyrethrum industry, and Dr H. F. Barnes went to Eire at the request of the Department of Agriculture to report on the heavy outbreak of wheat blossom midge and to discuss control measures. Dr. F. M. Roberts and Dr. T. Tinsley, of the Plant Pathology Department, continue their work for the Colonial Office in Zanzibar and the Gold Coast respectively, and Dr. J. Meiklejohn has been seconded for a year to survey and report on problems of soil microbiology in East Africa. Mr. M. J. Way has returned to Rothamsted after two years in Zanzibar where he did valuable work on a pest of coconuts. Under a scheme for the exchange of soil surveyors, Mr. B. W. Avery is spending a year in New Zealand. Dr. G. W. Cooke visited Belgium and the Netherlands to study recent developments in the production and testing of fertilizers. Dr. C. G. Butler was seconded during the winter to the Government of Ceylon, under the Colombo Plan, to advise on the development of bee-keeping. Dr. H. Greene spent a few months on soil work in the British territories in the Far East. Mr. J. A. Pollok resigned from the Soil Survey to take up the post of Director of the New Zealand Fertilizer Manufacturer's Research Association, and Dr. B. N. Singh was appointed head of the Department of Microbiology and Parasitology of the Central Drug Research Institute, Lucknow. Dr. C. B. Williams was elected President of the British Ecological Society.

Rothamsted was represented at the Second International Congress of Biochemistry in Paris, the Third International Congress of Phytopharmacy in Paris and the meetings of the Soil Chemistry and Soil Fertility Commissions of the International Society of Soil Science in Dublin. As a guest of the New York Academy of Sciences, Mr. F. C. Bawden attended a conference in New York on the nomenclature of viruses and rickettsia, and at the invitation of the University of California, Dr. D. M. C. MacEwan attended a conference on clays and clay technology.

Visitors

There were, as usual, many visitors to the Station both from this country and overseas. They included Sir Thomas Dugdale, Minister of Agriculture, Lord Carrington, Joint Parliamentary Secretary to the Ministry and Mr. F. H. Boland, the Irish Ambassador. Among the visitors from overseas were the Ministers of Agriculture from Belgium, Norway, Thailand and Trinidad, the Deputy Minister from Ontario, the Irish Minister for External Affairs and the Speaker of the Bombay Legislative Assembly. Numerous organizations visited the Station; they included the Executive Committee and Plant Quarantine Working Party of the European Plant Protection Organization. An international congress on Insect Populations was held under the auspices of the Comité Européen d'Etudes de Zoologie Agricole, and two courses on field experimentation were provided, one for the British Council, which was attended by many overseas workers, and the other for members of the National Agricultural Advisory Service.

Overseas scientists who spent some time at Rothamsted included Professor H. J. Brodie, of the University of Indiana, who worked in the Plant Pathology Department, Dr. Charles E. Kellogg, head of the United States Soil Survey, Dr. G. Smith of the U.S. Soil Survey, who was studying questions of soil classification, and Professor W. Kubiena from Madrid, the well-known soil scientist, who gave lectures and demonstrations on the microscopic techniques which he has developed for the study of soil morphology.

Buildings

The conversion of the Manor House into a Hall of Residence has been completed and has provided accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas.

The Work of the Station

The soil investigations fall into two groups, one dealing with rock weathering and the formation and classification of soils, and the other with soil fertility. In the Pedology Department the projects include a study of soil minerals and of the effect of organic compounds on their properties; a survey is being made in Lancashire of the occurrence of trace elements in both rocks and soils and of the distribution in certain clayey sedimentary rocks of molybdenum (an excess of which is known to cause the disease known as " teart " in cattle). Further investigations on ill-drained soils has shown the pronounced effect of even simple water extracts of plant materials on the movement of iron and aluminium in the soil profile. The work on certain Gold Coast soils reported in 1951 is about to be published and further investigations have been carried out on

soils from Tanganyika and the Sudan. In connection with a problem of poor sisal growth in Kenya a number of Black Cotton soils have been examined and poor growth has been found to be associated with a heavy black clay.

Investigations on fertilizer placement have been continued by the Chemistry Department. Experiments on potatoes carried out on 33 farms in the past two years gave about one ton per acre greater yield when the fertilizer was placed in contact with the seed or in a sideband than when it was broadcast before planting. The planting was done by machine from the flat. It would appear that two parts of placed fertilizer gave the same average yields as three parts broadcast. It was again noted that heavy dressings of fertilizer applied in actual contact with the seed sometimes checked early growth and on light soils slightly reduced the yields. For commercial machines a planting shoe with double walls on each side to serve as fertilizer coulters would be useful. Preliminary experiments on market garden crops showed some gains from placing fertilizers in sidebands. Further work has been done on "nitrophosphate" fertilizers in co-operation with the National Agricultural Advisory Service, the Northern Ireland Ministry of Agriculture and the Macaulay Institute. Experiments on potatoes and grass have been carried out with these materials prepared in three countries by somewhat different methods and they were found to differ in their effects; observations on the way in which the granules broke down in contact with moisture suggested that this may be due to methods of drying and granulating rather than to the different processes used to dissolve phosphate rock.

Further progress has been made with the problems of forest nurseries. "Partial sterilization" of the soils by formalin especially in old nurseries has again given excellent results. Other materials have also been tried and chloropicrin was found to be very promising. In one nursery with a substantial eelworm population, the numbers were greatly reduced by both these substances. In the past, serious losses of productivity of conifers have occurred in many Forestry Commission nurseries where calcareous seed-covers were commonly used until at our suggestion they were banned in 1947. Further evidence has been obtained that, even in a very acid heathland nursery, repeated applications of calcareous seed-covers are detrimental to Sitka spruce.

There has been much interest during the past year in synthetic soil conditioners and small-scale trials have been conducted at Rothamsted, at a number of farms in eastern England and in a few forest nurseries. These preliminary tests showed little effect on soil structure and no benefit to crop growth. Further work is necessary, however, before conclusions can be drawn.

A paper has been published giving the results of field experiments on liming carried out over a number of years in co-operation with the Advisory Soil Chemists. Various alternative liming materials including Magnesian limestone were used and it was shown that the type of material was unimportant and that, after taking into account the cost of transport and spreading, the ease of incorporation and allowance for subsidy, farmers should select the form which gives the desired neutralizing value at the lowest cost. It was also found

that there is no need to grind limestones more finely than is required to give 40 per cent through a 100-mesh sieve. This was fully as effective as equivalent amounts of burnt lime. Further progress has been made in investigations on soil organic matter and on the availability of manganese to plants. Radioactive phosphorus has been used in some preliminary field experiments to study phosphate fertilizer problems. Previous work on the chemical nature of soil nitrogen, which showed that at least 30-40 per cent. of the organic nitrogen was in the form of protein, was extended by an investigation of the amounts of amino-sugar nitrogen present in various soils. This showed that only 6-10 per cent. of soil nitrogen was in the form of amino sugars. The chemical nature of the rest of the non-protein nitrogen remains obscure. Some of it is in the form of nucleic acids but the major fraction appears to be combined with lignin-like complexes, and no satisfactory methods of investigating the chemical nature of this nitrogen are yet available.

In the Physics Department attention is being given to soil structure and further observations have been made on the effects of grass roots on this and on water movement in the soil. The experiments on deep and shallow ploughing and on irrigation have been continued and, again, substantial increases in yield have been obtained from irrigation particularly on early potatoes and grass. Equipment has been devized and built for the Plant Pathology Department to measure the water vapour of the air around the foliage of growing crops. This will facilitate studies of the atmospheric conditions which have a bearing on the spread of plant diseases. Other work includes investigations on the flocculation of clay minerals and on a method of determining " lime requirements " of soils. Following on the disastrous sea-flooding in February, 1953, gypsum is likely to be used to counteract the bad physical state of some of the heavier land. The correct rates of application can only be worked out from the results of soil tests, but whilst the principle underlying these tests was already known, recent research in the Physics Department has greatly reduced the time and trouble involved. These developments will enable the advisory services to handle many more samples than would otherwise have been possible.

Methods by which the soil's population of micro-organisms can be changed are important not only in soil fertility but also in the control of root diseases. One method is " partial sterilization " and the effects of formalin and of steam treatment on forest nursery soils are being studied in the Soil Microbiology Department. A study is also in progress of the effects of an antibiotic-producing organism (an actinomycete) on a fungus (*Fusarium culmorum*) which attacks plant roots. It appears that the fungus is checked not only by the antibiotic substance but by competition with the actinomycete for nutrients. The work previously reported on the breakdown by bacteria of insecticides, fungicides and herbicides when they reach the soil has been continued and progress has also been made with the study of bacterial activities in ill-drained soils. Investigations on the nodule organisms of leguminous plants continue to be one of the main projects in the department, and work has been done on competition between " virulent " strains capable

of infecting clover roots and "avirulent" strains which are incapable of doing so. This competition may have practical importance and is being further investigated. The influence of secretions from legume roots on the formation of nodules is also being studied and it has been found that the secretions from young seedlings stimulate nodule formation but those from older plants check it. It is not yet known whether this difference is due to the nature of the secretions or to the concentration.

In view of the amount of spraying with insecticides and fungicides which is now done and the introduction of overhead irrigation of crops in some parts of the country, information on the possibility of applying fertilizers in solutions sprayed on the leaves is desirable. Work on this subject by the Botany Department has been continued. In pot culture experiments, it was found that the uptake of any one nutrient from a solution sprayed on the leaves of sugar beet plants was independent of the presence or absence of other nutrients in the solution. It was also shown that nutrient uptake from the soil was affected by uptake through the leaves; plants sprayed with a solution supplying only nitrogen took up more phosphorus and potassium from the soil than plants sprayed with water, and spraying with solutions supplying potassium but no phosphorus increased the absorption of phosphorus by the roots. It was again shown that nutrients applied to the leaves are taken up about twice as efficiently as those applied to the soil. The possibility of increasing the protein content of sugar beet tops by spraying the leaves with a solution of nitrogenous fertilizer was further investigated in a field experiment. Solutions of ammonium nitrate or urea sprayed late in September doubled the yield of protein in the leaves at harvest in October. About 30 per cent. of the nitrogen applied was converted into leaf protein. The percentage of sugar in the roots was slightly reduced but the sugar yield was not significantly changed. As in the pot experiments, solutions sprayed on the ground at the same times were only about half as effective as the solutions sprayed on the leaves. A solution of ammonium nitrate sprayed on a field crop of wheat in May and June produced as great an increase in grain yield as the same amount of nitrogen applied as a top-dressing in April but had a much smaller effect on straw yield. In contrast with the experiments on sugar beet, the spray applications to the leaves were only slightly more effective than applications to the soil made at the same time. In the studies on the biology of wild oats, further work has been done on the effects of organic matter and of cultivation on germination.

In the Plant Pathology Department further work has been done on the spread of virus diseases. Exposing infected leaves to ultra-violet light gave results suggesting that viruses such as cabbage black ringspot, which are most frequently transmitted by aphids that feed only momentarily on infected leaves, occur mostly in the surface layer of cells. In field experiments the benefit of raising sugar beet stecklings in areas remote from other crops susceptible to sugar beet yellows was again demonstrated and the incidence of yellows was also reduced in other areas by raising stecklings in cover crops and by spraying with systemic insecticides. Experiments on cauliflower seedbeds showed that barrier strips of other

plants reduced the incidence of virus diseases and strips of wheat and barley proved the most effective.

Insecticidal sprays were tested for their effects in controlling various virus diseases with varied results. On cruciferous seedbeds they were valueless; on sugar beet they sometimes gave worthwhile results and sometimes did not and on potatoes they greatly reduced the incidence of leaf roll but had less effect on virus Y. Further studies have been made of the effects of fairly high temperature on susceptibility to viruses and it was found that when plants systemically infected with tomato bushy stunt, cucumber mosaic or carnation ringspot viruses were kept at 37° C. this produced seemingly healthy shoots and cuttings from such shoots often gave rise to virus-free plants. Obviously the virus content was much reduced but the treatment was insufficient to free the plants from virus in every case. The electron microscope has proved of great value in virus investigations and techniques for cutting sections have now been developed which enable tobacco mosaic virus to be seen in infected cells.

In the mycology section studies have been made of the spore and pollen content of the atmosphere and it has been shown that certain types of spore which were not supposed to occur in the air to any extent, are in fact often the predominant type. Previously unsuspected variations in the types of spores present in the air at different times of the day were also detected. Further work has been done on wheat diseases and large increases in yield have been obtained by controlling eyespot, take-all and weeds by various methods. On land infested by the eyespot fungus a wheat yield of 49 cwt. per acre, one of the highest recorded at Rothamsted, was obtained by sowing Bersée at 1½ bushels per acre, spraying with sulphuric acid and applying 4 cwt. per acre sulphate of ammonia in March. Decreasing the seed rate from 3 to 1½ bushels reduced lodging and increased the yield; the spraying reduced eyespot and lodging and increased the yield by 11 cwt. per acre.

In the investigations on cereal mildews it has been found that the later the spring crops are sown, the more they are affected and that increasing the growth rate of the crop, for instance by adding nitrogen, also raised the incidence of the disease. Further work was also done on potato blight and on club-root of cruciferous crops.

The main work of the Biochemistry Department has been an examination of a number of enzyme systems in the plant, particularly those that lead to a loss of infectivity in partly purified preparations. A study of this system should throw light on the factors controlling infectivity in the plant and so help in devising means for the direct treatment of plant virus diseases. There is so far no evidence about the nature of the actions involved. Other systems on which work is in progress include those responsible for the breakdown of nucleic acid and for the oxidation of a number of plant constituents such as amines, tryptophan, phenyl acetaldehyde, indoleacetic acid, and manganese. Many of these systems interact and the study of each throws light on the mechanism of the others. Another investigation is on the rôle that resistant parts of fungal mycelia may play in the building up of soil organic matter, and factors affecting the decomposition of the mycelium have been

studied. Amongst these is the use of mycelium as food by other organisms in the soil and in this connection the relationship between breakdown of the mycelium and the activities of the varied population of the soil is of interest. It has been shown, for example, that some nematodes causing plant diseases are able to break down fungal constituents as well as cellulose. In this work, too, it is becoming apparent that the subject of research cannot long remain isolated but rapidly develops connections with the work of other departments with a final gain to all concerned.

Eelworms parasitic on plants are microscopic in size, mostly transparent and rather inaccessibly buried in soil or plant tissue. At first glance many of these look alike, and very similar non-parasitic forms often occur along with them. In the Nematology Department much time is therefore being given to methods of collecting eelworms and identifying them. There are many species and within a species there are sometimes "races" practically identical in appearance but differing in their host plants and in their effects on these. With improved equipment and better techniques more accurate identification is now possible and this is helping greatly in the experimental work on eelworm control. One of the lines of work in the department is a study of the factors which influence the building up or decline of eelworm populations. In the potato root eelworm it was found that most of the seasonal increases in numbers occurred in July and August.

Further tests have been made in the control of this pest by chemicals and a recently-introduced soil fumigant 'chloro-bromopropylene" has been found to have a high lethal power, comparable with that of D.D. mixture, but these substances are expensive and none of them is wholly satisfactory. Ammoniacal gas liquor which has sometimes been suggested as a cheap source of nitrogenous manure was tested. The initial effect was to kill a considerable proportion of the eelworms present, but later the numbers increased rapidly and at the end of the season there were three and a half times as many eelworms in the treated plots as in the untreated. There are some varieties of the various agricultural crops which are more resistant to eelworm attack than others and efforts are being made to find resistant varieties, for instance in oats and potatoes. This search is complicated by the fact that different biological races of the same species of eelworm often have very different effects. One race may fail to enter a particular variety of a crop, another may enter but give rise to no symptoms and a third may produce symptoms of disease. In co-operation with Reading and Cambridge, investigations have been continued on the substances diffused from the roots of some plants which induce certain eelworm larvae to hatch and in the absence of suitable host plants they would starve. Some grasses are known to stimulate the hatching of potato root eelworm larvae and 14 species are at present being tested. Other work in the department includes the study of eelworms which cause galls on the roots of many plants. These root-knot eelworms used to be thought of mainly as glasshouse pests but recently they have been reported from rye grass in Wales and maram grass on the coast of Northumberland.

In the Entomology Department much attention continues to be given to aphids. It has been shown that their distribution in the air during periods of high wind is of greater importance than had previously been suspected. In collaboration with the Agricultural Department of the University of Nottingham, a study is being made of the effect of wind direction on aphis infestation of fields. The investigations of the effect of ladybirds and hoverflies as predators on the bean aphis is almost ready for publication. The work on earthworms has been continued, and it has been shown that the liming of acid soils usually causes a large increase in numbers. Wireworms are often abundant in permanent grassland and were major pests during the ploughing up campaigns of the two world wars. The war-time wireworm survey was chiefly concerned with the study of the susceptibility to wireworm attack of various arable crops and with recommendations for cropping infested fields, but ley farming is again on the increase and attention is being given to the rate at which the wireworm population builds up when arable land is put down to grass. It has generally been assumed that the increase in numbers is slow but investigations have shown that under grass there can be a build-up to the danger level in three years; under lucerne it is slower.

In the application of control measures against insect pests one of the problems is the risk of fresh infestation from weeds and neighbouring crops. This has been studied in the case of the swede midge which causes damage to many cruciferous crops. It can attack leaves, stems and inflorescences and amongst other damage is responsible for the unsightly " crumple leaf " and for loss of seed crops of various brassicas. It has now been shown that the swede midge can keep up its numbers by breeding on numerous cruciferous weeds and no fewer than eight completely new host plants have recently been discovered. Another important point is that certain other midges which attack various weeds and were supposed to be of different species have proved to be identical with the swede midge. Studies are also being made of the insects in some forest and old grassland soils and marked differences in species and numbers have been shown to be associated with degree of acidity and other soil conditions. The numbers in some cases are enormous, as many as 3,000 million, mainly mites, having been found in one forest soil.

The researches on the physiology and behaviour of the honeybee carried out in the past few years by the Bee Department are now finding application in problems of pollination and practical beekeeping. The conclusion has been reached that food-sharing takes place very widely amongst the bees of a colony and this almost certainly explains the heavy mortality that sometimes occurs when only a few foragers bring back to their hives small quantities of food contaminated with certain toxic substances. It has also an important bearing on the distribution of drugs fed to colonies in attempts to control disease. Again, food-sharing has been shown to be responsible for the development of individual colony odours which play a most important part in enabling the bees of a colony to distinguish between members of their own and other colonies. Another investigation deals with the problems of introducing queens

into strange colonies and of uniting colonies together. In this connection the way in which colonies of bees become " alerted " and commence to protect themselves against intruding workers from other colonies has been studied. It has been found that, with the exception of robber bees whom the guard bees attempt to seize and sting on sight, the fate of other intruders is almost entirely determined by the attitude they adopt when intercepted by the guards. Further work has been done on the effect of fertilizer treatments on nectar secretion in red clover in order to determine whether it is possible to increase the attractiveness of seed crops to pollinating insects. The composition of the nectars is also being studied. In co-operation with East Malling Research Station the same thing was done on apple trees and the results show that extra potash significantly increased the average quantity of sugar produced per flower, and that phosphate also possibly increased it, but that if adequate potash is present, nitrate tends to decrease it. The conclusion was reached that suitable fertilizer treatments increase the nectar yields of apple trees and hence their attractiveness to pollinating insects. Work has also been done on the foraging behaviour of bumblebees and on the relative efficiency of honeybees and various species of bumblebees as pollinators of red clover. On bee diseases, very interesting results have been obtained in the control of Nosema by a new antibiotic, fumagillin which was first used in Canada for this purpose. Large-scale field experiments have been commenced with this drug which appears to offer high promise of providing an efficient treatment for a widespread and serious disease. Work on European Foul Brood disease is also in progress. In bee-breeding a number of distinct strains have been maintained and multiplication of queens of two of these strains has been commenced. Other investigations in the department deal with swarming, pollen supplements, wintering and cluster formation.

In the Insecticides Department much attention has been given to investigations of the mode of action of the various kinds of insecticides. When poisons are applied as suspensions, particle size is of some importance in deciding the speed of action of the poisons. However, the size of the effect varies from one poison to another, depending on their physical properties, especially their speeds of solution in oils or waxes such as those found on the outside of the insects' bodies. Further work has been done on the way in which the organo-phosphorus group of insecticides kill insects by acting on their enzymes. The chemical constitution of insecticides derived from plants such as pyrethrum has been further studied and in collaboration with the Colonial Products Advisory Bureau the insecticidal activity of different strains of pyrethrum plant has been compared; attention is also being given to synthetic products related to these natural insecticides derived from plants. Other activities of the department include work on the toxicity of plant protective chemicals to honey bees and study of the changes in resistance to insecticides which occur in insect eggs as they develop. It is known that strains of insects are developing which are not readily killed by insecticides and this is being studied by applications of these substances at various concentrations to successive generations of

the survivors. On the field side, the experiments on the control of wireworms has been continued and successful results have been obtained by combine-drilling various insecticides with the seed. On beans, large increases in crop yield have been obtained by a single insecticide application at an early age of infestation of bean aphis; the effect on the parasite and the predators of the aphis is at the same time being studied.

The Statistics Department has continued its own researches on statistical methods and has also given much assistance to other Rothamsted departments in the planning and interpretation of their work. The experimental data on the manuring of field beans and on the effect of seed rate on yield of potatoes have been summarized. The department has devoted much time to assisting the Agricultural Research Council and the Ministry of Agriculture, particularly the National Agricultural Advisory Service. It has, for instance, played a large part in co-ordinating and analysing important series of experiments on the value of feeding antibiotics to pigs and on feeding iodinated casein and thyroxine to dairy cows. Reports were issued during the year on the Survey of Restored Opencast Coal Sites, and the Survey of Fertilizer Practice was continued in ten districts. The latter showed, amongst other things, that the large apparent decline in fertilizer consumption between 1950 and 1952 was partly due to the running down of stocks held by farmers and merchants. Work has continued on the Survey of Maincrop potatoes and there are in progress smaller surveys on animal diseases, farm tractor utilization and rabbit damage. As in the past, much work has been done for the Colonial Office and no fewer than thirty-one colonial officers visited the department for varying periods during the year. Results of twenty years' experiments on sugar cane in Trinidad have been summarized; similar work is being carried out for British Guiana and assistance has been given to the Overseas Food Corporation in connection with their field experiments on groundnuts.

The number of experimental plots on the Rothamsted and Woburn farms in 1952 was 3,124, of which about 500 were small plots testing fertilizer placement on vegetable crops and the effects of a soil conditioner on farm and market garden crops. The Classical experiments were continued on both farms; part of each of the permanent barley plots at Woburn was sown with winter barley as the spring barley suffers severely from competition with spurrey. The winter barley gave an excellent crop whilst the other was a partial failure. The experiment will be repeated in 1953 with the position of the two varieties changed. The ley-arable experiment is now giving measurements of fertility differences due to the various grasses and legumes ploughed in and a new three-course rotation designed to study further the long-period effects of applications of raw straw to arable land was begun in 1952. The annual experiments included four on fertilizer placement, three on tests of "Nitrochalk" and nine on the field study of plant disease problems. Four other large experiments were concerned with farmyard manure and its residual effects, methods of fertilizer application to potatoes planted by machine and the top-dressing of cereals with nitrogen late in the season when the crop is in ear.

The results of these last experiments were closely in line with previous ones, although in 1952 the late nitrogen was, on the whole, less effective in increasing the protein than in the two previous seasons. Early varieties of hybrid maize were again tested at Woburn and good yields were obtained in spite of poor ripening weather. The results brought out the importance of sowing as soon as the soil is warm enough for satisfactory germination. Crops of 14-16 tons per acre of green material were obtained from yellow sweet lupins (variety Weiko), which appears to have some promise as a fodder crop for acid soils and tests of birdsfoot trefoil were continued.

The scientific departments have, as before, had willing co-operation and valuable assistance from the farm manager and his staff.

PHYSICS DEPARTMENT

R. K. Schofield

R. K. Schofield was on leave of absence during the first half of the year while completing the tenure of a six months' appointment as Visiting Professor in Soil Physics in the Department of Agronomy at Cornell University. With the help of a travel grant from the Agricultural Research Council he also visited 22 other research centres in the United States and 3 in Canada. During these visits he had stimulating discussions on the extent to which meteorological data can serve as a practical basis for the control of irrigation, and on physico-chemical equilibria in soil. He wishes to record his sincere thanks to Dr. Richard Bradfield and many others who helped to make his time in America so profitable and enjoyable.

H. L. Penman returned in May from his six months' visit to Australia where about two-thirds of his time was spent at the Waite Agricultural Research Institute and the remainder in visits. These included an expedition to Lake Eyre in the " Dead Heart of Australia," a visit to a large sheep station in one of the semi-arid regions, many visits to research farms and orchards in intermediate rainfall regions, and inspection of engineering works in progress in the construction of reservoirs in the wet Victorian mountain regions. A tour of the Murray and Murrumbidgee irrigation areas was based on two- and three-day periods spent at the Commonwealth Scientific and Industrial Research Organization irrigation research stations at Merbein, Griffith and Deniliquin. From all these experiences, supplemented by formal talks and informal discussions a broad picture, detailed in parts, was obtained of the water problem in a range of climates all more extreme than that of the British Isles. On fundamentals most was abstracted from extended visits to the Commonwealth Scientific and Industrial Research Organization Division of Meteorological Physics where fine work is being done on the physics of the evaporation process, and from the Plant Physiology Department at the Waite Institute where an important school in the study of plant transpiration is being built up.

While away he was awarded a Darton Prize by the Royal Meteorological Society for his paper on " Evaporation over the British Isles." Since his return he has served on the Hydrology Research Group of the Institution of Water Engineers, the Working Party on Irrigation of the Ministry of Agriculture and attended the London Meetings of U.N.E.S.C.O. Arid Zone Research Committee as honorary consultant.

G. H. Cashen acted as Head of Department during the absence of R. K. Schofield and H. L. Penman. A. W. Taylor, who had been in receipt of a Research Grant from the Agricultural Research Council, was appointed in October, 1952 to fill the vacancy caused by the resignation of W. C. A. Hutchinson. J. P. Quirk received the Ph.D. degree of London University, and returned to resume his duties with the Division of Soils of the Australian Commonwealth Scientific and Industrial Research Organization. R. L. Closs spent three months studying temperature gradients immediately above

and below the ground surface before returning to New Zealand; G. M. F. Grundy spent six months studying soil structure and physical chemistry before taking up an appointment in Malaya. I. R. Cowan has joined the department for one year in preparation for work in Jamaica on the irrigation of sugar cane; T. E. Tomlinson is studying soil physical chemistry for some months before taking up a research appointment in Sierra Leone.

Soil Cultivation

Deep ploughing

A full account of the results of the deep ploughing experiment at Rothamsted will be prepared when the second rotation is completed in 1955. Meanwhile only brief accounts will be given in these reports. In a season when potato yields were depressed by dry weather in June and July, the yields on all deep-ploughed plots were more than a ton per acre less than on the shallow ploughed plots. This result is very like that of 1951 in rather similar weather conditions. The marked depressions of these two years largely offset the small but consistent benefits reported for the first seven years. As usual deep ploughing has not affected the yields of cereals or the one-year grass ley. The results for sugar beet are not yet to hand owing to delay in lifting.

Agricultural Meteorology

Irrigation

The account of the sugar beet experiments has been published.

The Woburn experiment on grass, sugar beet, early potatoes followed by cabbage and barley has been kept going in spite of a shortage of assistance, but only at the level of a primary field experiment. It has not yet been possible to start the study of the physical and biological effects of irrigation on the soil and on plant growth as was planned.

The season was wet up to mid-May, then dry up to the end of July and wet thereafter. During the dry period water could not be put on frequently enough so most of the soil moisture deficits grew larger than was planned. For the rotation crops the four treatments were simplified: O, no irrigation; C, irrigation throughout the season to try and maintain the deficit near one inch; A, irrigation in the first half of the season equal to C and then no more; B, no irrigation in the first half of the season and then irrigation as in C. For grass, increasing amounts of irrigation were given in the order A, B, C. Brief notes on each crop follow.

Grass. Yields increased with water applied. Between mid-June and mid-August the O plots were brown and gave no yield. By mid-September all plots were even in colour and about equal in yield.

Sugar beet. Early watering appeared to be slightly harmful.

Barley. Total water was limited by lodging. Late watering was better than early; early and late was better than either.

Potatoes. Early watering was much better than late: early and late better than either.

The following table shows the yields for the watering extremes at two levels of nitrogen dressing.

Woburn Irrigation 1952

Crop	Period	Rain (in.)	Irrigation (inches)	Plot		Yield
Grass ..	Apr. 28–Sept. 29	9·6	—	ON_1	68·1	cwt. per acre
				ON_2	66·2	(hay, 7 cuts)
		9·6	5·1	CN_1	97·8	
				CN_2	103·5	
Sugar Beet	Apr. 28–Sept. 29	9·6	—	ON_1	47·1	cwt. per acre
				ON_2	55·5	(sugar)
		9·6	5·6	CN_1	57·7	
				CN_2	59·6	
Barley ..	Apr. 28–Aug. 18	7·0	—	ON_1	21·6	cwt. per acre
				ON_2	23·0	(grain)
		7·0	2·9	CN_1	22·8	
				CN_2	27·3	
Potatoes	Apr. 28–July 7	4·0	—	ON_1	6·0	tons per acre
				ON_2	6·2	
		4·0	2·7	CN_1	9·7	
				CN_2	10·9	

Evaporation and transpiration

Hitherto all our theoretical estimates of transpiration have been based on an empirical conversion factor expressing the ratio of potential transpiration to open water evaporation. The theory has now been extended so that potential transpiration can be estimated directly from weather data. Tests, mainly on Australian data, have been encouraging, but their success depends upon a correct value for a new empirical factor—the diffusive conductance of the leaf stomata. Geographical, seasonal and climatic factors are eliminated and only this plant constant remains, and in a few years' time this, too, should be known when techniques, now in development, are perfected for measuring it directly. At the same time, an attempt has been made to deal with the complex but important case of orchard irrigation, again with promising results.

For the present these new developments are primarily of benefit in clearing up ideas on the fundamentals of the problem: in our own work of the immediate future we shall continue to use the empirical conversion factor. In one application, a Working Party of the Ministry of Agriculture is drawing up a Technical Bulletin setting out the need for irrigation in Great Britain: in a second it has been used as the basis for a contribution on Evaporation in a symposium on Hydrology organized by the Institution of Water Engineers.

Micro-climatology

Throughout the summer I. F. Long has built and maintained thermistor equipment giving continuous records of dry bulb and wet bulb temperatures at six heights within and above a potato crop. Some of the records have been analyzed in detail to give half-hourly values of water vapour pressure gradients from the ground up to 160 cm. during days when a dew balance, set up by J. M. Hirst (Plant Pathology Department) was in use. On nights of dew, there were three phases on the records: formation, a steady period, and then re-evaporation. These are represented in the

humidity profiles by a vapour pressure increasing from *c.* 40 cm. upward, no gradient, and vapour pressure decreasing upward.

This valuable piece of preliminary work offers possibilities of expansion to reveal more of the physical processes involved in condensation of water on potato leaves and its importance in the germination of potato blight spores. A similar set of equipment has been built for use at Woburn on the irrigation experiments.

Heat flow and water flow in the soil

J. S. G. McCulloch has worked on this problem at the soil cylinders in the meteorological enclosure and in the laboratory with small soil columns. Previously we had recorded rises in the water table (at about 24 in. below turf) early in the morning and attributed them to an increase in soil temperature. After failure of attempts to reproduce the effect by artificially applying heat to the soil surface, it was found that the main features of the earlier records were due to thermal expansions in the recording apparatus. Nevertheless, subsequent experiments in the laboratory have shown a small but real effect of temperature on the equilibrium distribution of water in a vertical column of soil. Experiments are now in progress to determine whether differential thermal expansions and the effect of temperature on surface tension provide a satisfactory explanation.

Soil Physics

Soil structure and grass roots

In an attempt to make use of last year's observation that the metaxylem vessels of severed grass roots conduct water, very shallow roto-tilling was compared with ploughing-out old grassland as an autumn seedbed preparation for spring wheat. Unfortunately, under the wet winter conditions, even repeated rototilling did not kill the grass which competed too strongly with the wheat. By comparing suctions developed in the surface soil both on thin plots and on de-turfed patches on grass plots it was shown that the roots do, in fact, conduct water upwards. It seems, however, that the effect of this on germination will be small except in a very dry spring.

Water entry into sand

Experiments on the rate of water movement into dry sand have shown the importance of the contact angle, sand-water. As a first step, work is being carried out on the simpler glass-water system.

Interaction of water and soil crumbs

It has been found that the moisture content and cohesion of soil crumbs vary continuously with their rate of wetting. At the higher rates the crumbs are disrupted by the escape of entrapped air. When repeated under vacuum, different rates of wetting had no effect on cohesion, indicating that uneven swelling is an unimportant factor. The work shows that at low suctions it is impossible to infer the suction of a soil sample from its moisture content unless the rate of wetting is known. Further, it brings out one of the uncontrolled variables in the Yoder wet sieving technique, which is frequently used as a criterion of good soil structure.

Equilibrium thickness of water films

Attention has again been given to the problem presented by the results of Deryagin and Kussakov who measured optically the thickness of films of liquids on solid surfaces. For pure water on mica and glass the results agree with those to be expected from Gouy's theory, but when dilute NaCl solutions were used the films were found to be much thicker than expected. G. H. Cashen has set up similar optical apparatus, and has broadly confirmed the earlier results using pure water. While he has not succeeded in obtaining satisfactory results with NaCl solutions, his attempts have led to an appreciation of the cause of the trouble. When a solution is used, concentration gradients develop in the initial stages of the experiment which are only slowly reduced by ionic diffusion. It is now clear that very elaborate apparatus would be required to ensure complete equilibrium of both salt and water as assumed in the theory.

A more promising line of approach has been opened up by J. P Quirk who observed that when orientated aggregates of Na-montmorillonite are placed in NaCl solutions of different strengths they spontaneously disperse when the concentration is less than N/100. From N/100 to N/3·16 the degree of swelling which K. Norrish, of the Pedology Department, measured by X-ray diffraction is inversely proportional to the square root of the salt concentration. Calculations, based on Gouy's theory, give repulsion pressures ranging from 10^5, dynes/cm.^{2}, in N/100 NaCl when the platelets are separated by 160 A to 3×10^6, dynes/cm. in N/3·16 when the separation is 28 A. The balancing attractive force thus appears to vary inversely as the square of the distance.

Physical Chemistry

Physico-chemical determinations on soil samples

A. W. Taylor's work has again centred round the use of 0·01 M $CaCl_2$ solution in the physico-chemical testing of soil samples. Using the theoretical approach first introduced by Gouy it has been estimated that when a sample of almost any soil from the humid temperate zone is suspended in this solution the value of pH-$\frac{1}{2}$p (Ca+Mg), which we call the " lime potential," is less than 0·02 greater than the limiting value obtained at lower concentrations. Hence it can conveniently be determined in this way to a degree of accuracy which is ample for most practical purposes. It would be inconvenient to use a concentration much below 0·01 M, while the uncertainties introduced by the use of a solution much stronger than 0·01 M are greater and more variable from soil to soil.

In response to a suggestion received from the National Agricultural Advisory Service the method devised earlier by R. K. Schofield for measuring " lime requirement " has been modified so as to give the amount of alkali taken up by a soil sample to bring its " lime potential " up to 5. This potential is about one unit lower than that usually found in soils containing free calcium carbonate. In the modified method cacodylic acid is used in place of *p*-nitrophenol and the determination is speeded by using pH measurements in place of titrations. The method has given encouraging results with soil samples taken from liming trials laid out by the National Agricultural Advisory Service, but it must still be regarded as tentative.

Distribution of positive and negative charges on crystals of kaolinite

The clay mineral kaolinite is a major constituent of many soils of the tropics and sub-tropics and china clay, which is almost pure kaolinite, is a material with many industrial uses. From the results of X-ray analysis a clear picture has been formed of the atomic arrangement within the crystal lattice, and from electron micrographs it is known that typical crystals have the form of thin hexagonal plates, but the location and origin of the electric charges carried by the crystals has not been established. Yet there can be little doubt that these charges influence the structure and the erodability of kaolinitic soils and the consistency of ceramic bodies and slips. Our understanding of the physical behaviour of kaolinite is incomplete so long as we lack precise knowledge about these charges.

Techniques devised earlier by R. K. Schofield have been successfully applied to this problem by H. R. Samson and, for the first time, a picture has emerged which appears to cover all the known facts. The electric charges arise from two quite distinct causes. One is the replacement within the body of the crystal of Al^{3+} for Si^{4+} and possibly Mg^{2+} or Fe^{2+} for Al^{3+}: each replacement of this kind gives rise to one unit of negative charge. Mild treatment with acid or alkali at room temperature does not alter these charges. The other cause is the exposure of oxygen atoms at the edge faces which, being bonded to fewer Si and Al atoms than oxygens in the body of the lattice can each form an additional bond with a hydrion. The extent to which these additional bonds are formed depends on the degree of acidity. If on an average only two-thirds of the possible bonds are formed the edge faces will be uncharged: if more than two-thirds are formed they will be positively charged; while if less than two-thirds are formed they will be negatively charged.

The condition brought about by washing kaolinite first with N. NaCl containing N./100 HCl and then with water is especially interesting, as typical samples remain strongly flocculated after all the salt has been washed out. In this condition the crystals retain exchangeable sodium ions, showing that they are on the whole negatively charged. Samson's discovery that these flocculated kaolinites absorb small amounts of chloride from very dilute salt solutions is readily explained if the edge faces are positively charged under these rather acid conditions. The flocculation in the absence of salt is also explicable as due to the attraction of the positively charged edge of one crystal to the overall negative charge of a neighbouring crystal.

The addition of more than a critical amount of NaOH brings about two changes: the kaolinite is deflocculated in the absence of salt, and it repels chloride when NaCl is added. Both effects are explained by the disappearance of positive charges from the edge faces. These positive charges can also be neutralized by the addition of oxalates, phosphates, alginates and even Na montmorillonite. When sufficient has been added to bring about deflocculation the kaolinite has no longer the power to attract chloride ions.

This work is of immediate value in opening up a very promising line of approach to the study of kaolinite and other clay minerals. In the long run it should yield information about the stability of kaolinitic soils. This may be particularly valuable in the tropics and sub-tropics.

CHEMISTRY DEPARTMENT

E. M. Crowther

Fertilizer and Other Field Investigations

The supply position for sulphuric acid from sulphur, pyrites or anhydrite has eased, at least temporarily, and the reintroduction of subsidies on inorganic nitrogen and phosphorus fertilizers has restored the balance between prices of fertilizers and crops. The need for increasing the output of British farms and, at the same time, of keeping down imports of raw materials requires continued work on improved methods for making and using fertilizers. Some of the new processes under consideration yield products containing little water-soluble phosphorus, and it is therefore necessary, before these processes are adopted on a large scale, to ascertain the agricultural value of the products under a variety of conditions. For some crops considerable economy can be obtained by placing fertilizer close, but not too close, to the seed. Superphosphate, alone or in mixtures, is now commonly drilled with cereals, but for other crops drilling fertilizer with the seed or sets may be unsafe. For some crops controlled placement in bands at a safe distance from the seed has marked advantages but for other crops broadcasting remains an excellent method. Until the rules are worked out in detail there is little prospect of manufacturers producing the kinds of machines which will allow farmers and market gardeners to obtain the benefits of controlled placement of fertilizers.

Fertilizer placement

In extending earlier work G. W. Cooke, with M. V. Jackson and F. V. Widdowson, carried out in 1952 nineteen further field experiments comparing broadcast and placed fertilizers for potatoes planted by machines. The planter was used on flat land, planting the potatoes and covering them with a ridge of soil after applying the fertilizer. Early dressings of broadcast fertilizer cultivated deeply into the seedbed were compared with late dressings broadcast on the surface, immediately before planting, and with dressings placed either in contact with the seed or in a sideband below the level of the seed. National Compound No. 1A (8 per cent. N., 6 per cent P_2O_5, 10·5 per cent K_2O) was tested at 7·5 and 15 cwt. per acre by each of these four methods.

On the average of all the experiments, placed fertilizer gave much higher yields than broadcast fertilizer. There was no advantage from early broadcasting, before cultivating to prepare the seedbed, over late broadcasting. At the lower rate fertilizer placed in contact with the seed gave slightly higher mean yields than fertilizer in a band at the side of the seed; at the higher rate contact placement was slightly inferior to sideband placement.

The mean yields of 14 experiments in 1951 and of 19 experiments in 1952, averaging rates of application, were :

Mean yields, tons per acre

	1951	1952
Broadcast early	—	8·8
Broadcast late	10·1	8·9
Placed in contact	11·1	9·8
Placed in sideband	11·0	9·8
No fertilizer	7·4	5·7

In both years placed fertilizer gave about one ton per acre more potatoes than the same amount of fertilizer broadcast. The relative efficiencies of the various methods of application, obtained by graphical interpolation from a smooth curve, taking sideband placement as the standard, were :

Relative efficiencies of methods of applying fertilizer

	1951		1952	
Method	Low rate	High rate	Low rate	High rate
Broadcast early	—	—	57	63
Broadcast late	50	68	61	67
Placed in contact .. .. Over	100	Over 100	113	87
Placed in sideband	100	100	100	100

In each season fertilizer broadcast on the seedbed was inferior to placed fertilizer, two parts of placed fertilizer giving about the same yield as three parts of broadcast fertilizer. In both years placement was superior to broadcasting in more than three-quarters of the experiments, the differences being significant at about half of the centres.

In both years emergence and early growth of potatoes were depressed at most centres by the heavier dressings placed in contact with the seed, but, later, the crops recovered from the early check. At both rates in 1951 and at the lower rate in 1952, placement in contact with the sets gave higher yields than placement in sidebands. In 1952 the higher dressing placed in contact with the sets gave slightly lower yields on light soils than when placed in sidebands, but there was little difference between the two methods of placement on heavy land. With heavy dressings there is some risk of lower yields from contact placement on light land and in dry summers. There is need for a planting shoe with double walls to serve as fertilizer coulters on each side of the shoe. Such an arrangement might allow heavy dressings of fertilizer to be applied with safety even on light soils and, through economy in fertilizers, should prove worthwhile, even for farmers with only moderate acreages of potatoes.

G. W. Cooke with M. V. Jackson carried out preliminary experiments on fertilizer placement for horticultural crops at Rothamsted and at Luddington Experimental Horticulture Station (in collaboration with H. Fairbank and N. D. Goodway). Several of the crops suffered from drought. At Luddington, where both broadcast and placed fertilizer (National Compound No. 1A) increased yields of onions, placed fertilizers gave the higher yield. At Rothamsted a granular fertilizer containing 14 per cent P_2O_5 and 14 per cent K_2O gave much higher yields of broad beans when placed than when broadcast. At both centres National Compound No. 1A gave higher yields and earlier crops of lettuce when placed than when broadcast.

In an experiment on spring beans at Rothamsted superphosphate had little effect whether broadcast or placed: potassium sulphate gave a small increase when broadcast and a large one when placed. In a lucerne experiment at Rothamsted, P, K and PK fertilizers were tested as dressings broadcast before and after the final ploughing in preparing the seedbed. The effect of a " starter-dose " of superphosphate drilled directly below the seed was tested in conjunction with all the other treatments. The " starter-dose " gave much better early growth and yields than the broadcast dressings. The ploughed-in dressings gave slightly higher yields than the seedbed dressings in the first but not in the second cutting.

Alternatives to superphosphate

One alternative to using sulphuric acid for making superphosphate is to dissolve the phosphate rock in nitric acid and then to add ammonia to form a mixture containing mainly ammonium nitrate and dicalcium phosphate. To improve the condition of the mixture it is necessary, in addition, either to remove excess calcium nitrate, to add ammonium sulphate or to use a mixture of sulphuric and nitric acids in place of nitric acid alone. Materials prepared in these ways are now known as " Nitrophosphates." Various kinds of product need to be tested under many agricultural conditions before their agricultural value can be adequately assessed and the best conditions determined for their preparation.

In three experiments on spring-sown barley in 1952, G. W. Cooke with M. V. Jackson and F. V. Widdowson compared a " Nitrophosphate " (prepared with addition of ammonium sulphate) against an equivalent mixture of granular superphosphate and " Nitro-Chalk ", the fertilizers being applied broadcast and also by combine-drill. On the average, the broadcast superphosphate mixture was superior to the broadcast " Nitrophosphate," but when combine-drilled both kinds of fertilizer gave similar yields. From these preliminary experiments it would appear that a " Nitrophosphate " with equal proportions of N and P_2O_5 would be suitable for drilling with spring cereals.

Two series of co-operative field experiments, initiated by the Fertilizer Conference of the Agricultural Research Council and planned and co-ordinated from Rothamsted, were continued in 1952. The field work was carried out under the direction of Soil Chemists of the National Agricultural Advisory Service and the staffs of the Northern Ireland Ministry of Agriculture, the Macaulay Institute for Soil Research and Rothamsted Experimental Station.

In the first series, on the average of nine potato experiments, yields decreased in the order superphosphate, dicalcium phosphate, silicophosphate and Gafsa rock phosphate.

The second series of experiments tested three kinds of " Nitrophosphate," prepared in three countries. All plots received equal amounts of N and K and the tests were therefore concerned with the availability of the P. On the average of nine experiments on grass cut for hay or silage, a " Nitrophosphate " made with addition of ammonium sulphate gave yields rather better than those from equivalent superphosphate; a " Nitrophosphate " made with mixed nitric and sulphuric acids was about two-thirds as effective as

equivalent superphosphate; a " Nitrophosphate " made by removing surplus calcium nitrate was much inferior to the other forms and gave very little response. Closely similar results were obtained in ten experiments on potatoes.

It is not by any means certain that these results depend on essential features of the processes by which the various " Nitrophosphates " were made. We noticed that there were marked differences in the physical properties of the granules and that these did not remain constant from year to year in products from a single factory. In some of the preparations the granules slaked rapidly, whilst in others the granules remained hard and compact. It is possible that the rate at which dicalcium phosphate enters or moves within the soil may be influenced by the speed with which the granules break down in contact with moisture. This property may depend on details in the drying or granulating processes rather than on the general method of preparation. Investigations on new kinds of fertilizers are inevitably complicated by the circumstance that the methods of preparation have not been stabilized. Indeed, the agricultural investigations sometimes reveal possible improvements in production methods, at the cost to the experimenter of having different kinds of material in successive years of what may originally have been intended to be a uniform series of repeated experiments.

By-product ammonium sulphate

G. W. Cooke and J. K. Gasser made preliminary observational tests on a sample of ammonium sulphate prepared at a gasworks by a new process in which 69 per cent of the S was as sulphate, 12 per cent as sulphite and 18 per cent as thiosulphate. The product, which was in poor mechanical condition, was applied in heavy dressings to grass, cereals, potatoes and market garden crops to test possible toxic effects in comparison with ordinary commercial ammonium sulphate. In one experiment on wheat early growth was poor with the by-product and in one experiment on grass the foliage was slightly burnt but in many other experiments there were no signs of damage or reduced growth. If by-product fertilizers, difficult to apply or containing materials likely to be harmful, are to be used in agriculture, they must be offered at greatly reduced prices.

Nutrition problems in forest nurseries

Investigations in collaboration with the Research Branch of the Forestry Commission were continued. The background of the work and some of the main findings were reviewed in the Rothamsted Report for 1949. Annual summaries are published in the Forestry Commission's " Reports on Forest Research." B. Benzian was in charge of the experiments in several nurseries and forests and R. G. Warren, H. A. Smith and J. E. A. Ogborn of associated laboratory work. The Soil Microbiology and the Nematology Departments made special investigations on biological aspects of certain problems arising in the course of the work.

In experiments at several nurseries in each of seven seasons we have had marked improvements from treating the soil with formalin

solutions at least three weeks before sowing Sitka spruce or other conifers. The results have improved as we gained experience on the best times and methods of applying the formalin. A successful treatment has been to apply 250 ml. of formalin per square yard, after diluting to such a volume, often 5 l., as the soil can take up quickly. It was found in three nurseries that formalin applications in December 1951 were even better than those given in February 1952. It would be difficult to apply the formalin treatment on a commercial scale, on account of the large volumes of water needed. We have continued our search for alternative materials, partly in the hope of finding something more convenient on a large scale and partly because materials with more specific effects than formalin might throw light on some of the major factors involved in the effects of soil disinfection under various conditions. In 1952 injection of neat formalin at 9 inch centres gave only very small improvements at two nurseries, with fair results at a third. Paraformaldehyde was ineffective in 1952. From past failures with a variety of fungicides in field and pot experiments it seemed likely that a major difficulty was to secure intimate incorporation of the active material throughout the whole mass of surface soil. It was therefore decided to test a number of volatile fumigants. Chlorpicrin, injected in February in about 2 ml. doses at 9 inch centres, gave significantly better results than formalin solutions in each of three nurseries in which it was tested. Chlorpicrin also gave good results in pot experiments on soils from three nurseries. Ethylene dibromide failed in the pots and in two of the three nurseries, but it gave marked improvements in Ringwood nursery, which is known to carry a much heavier population of nematodes than the other nurseries in which we have made experiments. J. B. Goodey's examination of plants from experiments in the Ringwood nursery showed that formalin, chlorpicrin and ethylene dibromide greatly reduced the numbers of the nematode *Hoplolaimus uniformis* on first-year Sitka spruce seedlings. There were also differences associated with manurial treatments. In another experiment in the same nursery transplants growing on untreated plots carried a heavy infestation of the same nematode, whilst those on plots previously treated with formalin were completely free of it.

D.D., a chlorinated propane and propylene, checked " damping-off " and improved growth of Sitka spruce seedlings in pots. It will be tested in field experiments against other fumigants and formalin, at various intervals before sowing.

Formalin solutions applied two months before lining-out markedly improved the growth of Sitka spruce transplants in several nurseries. In one nursery the formalin treatment of transplant beds was deliberately postponed until a month before lining-out to avoid chemical reactions with another factorial soil treatment in the experiment. The results were disastrous: most of the plants on the formalin plots were killed. Although the disinfection or fumigation of transplant beds has great promise and some theoretical interest in confirming that the benefits from formalin treatment do not depend primarily on checking early " damping-off," the technical details must be worked out more fully before the method can be used safely for transplants.

Seedlings raised on formalin treated plots have behaved very well in transplant beds and in forest plantings. Each year representative plants from experiments in several nurseries have been examined for mycorrhiza by Dr. I. Levisohn of Bedford College, but no clear relationships have so far been found between nursery treatments and the occurrence of mycorrhiza. A large number of representative plants are examined each year at Rothamsted for gross morphological features. It is common to find that poor plants from plots without disinfectants show signs of damage to the tap root and laterals. They also often have long black roots, presumably infected by pathological fungi. Sometimes it appears that fine fibrous roots arise through repeated damage and are not necessarily a sign of favourable conditions and vigour.

Sowing was unavoidably late at all nurseries in 1952 and this may have introduced some abnormal features. A number of visual symptoms were either different from or occurred much later than in most of the preceding years. An acute general yellowing of transplants on plots known to be potassium-deficient was observed at Wareham for the first time since 1946. The yellowing and hardening of the younger needles, shown by responses to manurial treatments to be a symptom of magnesium deficiency, did not appear in 1952 until late in October and were much less marked than in earlier years. The usual purplings from potassium deficiency were general on plots lacking this element in certain compost and fertilizer treatments.

An experiment started on very acid soil in Sugar Hill Nursery, Wareham in 1948 received eight kinds of seed-covers for four successive crops of one-year Sitka spruce seedlings. The fifth crop in 1952 received a uniform quartz cover to measure the residual effects of the earlier treatments. The residues from four covers containing considerable amounts of calcium carbonate as limestone or shell fragments gave much poorer growth of Sitka spruce seedlings than covers free from calcium carbonate. In this experiment we reproduced a set of conditions which in the past had led to serious losses of productivity in many nurseries. Calcareous seed-covers were used quite frequently before the autumn of 1947 when, on our recommendation, they were banned from Forestry Commission's Nurseries.

Many experiments indicate, without completely establishing, that the benefits from keeping conifer nurseries very acid and from using soil disinfectants in the old nurseries depend in part on maintaining a supply of ammonium nitrogen in place of nitrate nitrogen. In one experiment continued for four seasons in an old neutral nursery, repeated dressings of ammonium sulphate gave better Sitka spruce seedlings than equivalent dressings of " Nitro-Chalk." In new experiments in 1952 in two old nurseries the heights decreased in the order ammonium sulphate, " Nitro-Chalk," calcium nitrate—for equivalent top-dressings; the differences were small and irregular in newer acid nurseries.

In an experiment at Wareham, which has run for four seasons with two years' grass ley followed by two successive crops of one-year Sitka spruce seedlings, the first crops of Sitka spruce have been much poorer than the second crops. Observations on irregularities

in other experiments in this nursery, on a site which had carried ley two years previously, suggest that the grass root residues decompose very slowly and, in some way, interfere with the normal growth of Sitka spruce seedlings. In a large rotation experiment started in Kennington nursery in 1951 the Sitka spruce seedlings of 1952 were poorer after green crops in 1951 than after the Sitka spruce in that year. A parallel experiment at Wareham showed only small differences. In two earlier series of rotation experiments there was little benefit from resting conifer seedbeds under green crops or leys.

In an experiment continued for five seasons on very acid poor soil at Bagley Wood, plots with fertilizers gave rather better average mean heights than plots with a standard compost of bracken and hopwaste, but the fertilizers were slightly inferior to the compost in one season of prolonged drought. The best growth over all seasons was from special composts prepared by loading either straw or bracken with heavy dressings of fertilizers. The progressive improvement of the plots with time decreased in the order: composts made with fertilizers, heavy fertilizer, ordinary composts, light fertilizer, raw organic wastes with fertilizers, unmanured. This series suggests that most of the observed differences can be ascribed to the nutrients in the composts and fertilizers with little additional benefit from the organic matter as such.

Soil conditioners

G. W. Cooke and his colleagues carried out small-scale trials on thirteen farms in Eastern England to test the effects of a soil conditioner (the sodium salt of a hydrolyzed polyacrylonitrile, supplied as " Krilium CRD-189 ") on potatoes. The tests, which adjoined other fertilizer experiments, consisted of four very small plots, each of two rows of potatoes six feet long. One diagonally opposite pair of plots received the conditioner, which was carefully forked in at the rate of 600 lb. per acre, no filler being used. No differences in soil structure or in crop growth were observed in repeated inspections during the season but, when the potatoes were lifted, the soil at two centres appeared to have better structure on the treated plots. The yields from such small plots are inevitably uncertain but the over-all average yields of 11·6 tons per acre with soil conditioner and 11·2 tons per acre without soil conditioner give little indication of any general benefit.

B. Benzian carried out three small-scale experiments in forest nurseries, in association with the Research Branch of the Forestry Commission, to test the soil conditioner at the rate of 3 cwt. per acre, carefully incorporated into the surface by forking, raked into the surface inch after forking, and applied in both ways. The soils were fine sands or sandy loams. No visible effects on soil structure or crop growth were observed at any stage, apart from some inferiority in growth following the surface application in one nursery.

The above experiments were made with direct applications of the active material without diluent or filler. Its hygroscopic nature may have interfered with intimate incorporation. It would appear that improved methods of preparation and application must be devised before synthetic soil conditioners can be expected to improve crop growth under normal agricultural or horticultural conditions.

Liming materials

E. M. Crowther and T. W. Walker published a summary of several series of field experiments carried out by soil chemists of the National Agricultural Advisory Service on the relative values of alternative liming materials. The standard rate of application was generally determined by the Hutchinson-McLennan " lime requirement " method. On the average of large numbers of experiments, crop yields were doubled by liming materials applied at the standard rate, but lower rates of application were highly effective. On the average, dressings at half of the standard rate gave 85 per cent of the crop increases obtained from the standard rate. Although the full rate of dressing may sometimes prove profitable, especially as a long-term investment, there must be large areas of land which would give a very high return from quite modest applications of liming materials. On many farms with acid soils it would be a better investment to work round most of the fields quickly with light dressings than to proceed piecemeal with heavy ones.

Experiments with specially prepared size-fractions of limestone showed that materials passing a sieve with 40 meshes per inch gave yields close to those from equivalent amounts of burnt lime. Even coarse fractions (with only 9 per cent passing a 40-mesh sieve) were better than half the equivalent amounts of burnt lime. There is no need in practice to grind limestones more finely than is required to give 40 per cent through a 100-mesh sieve. Such limestones gave, on the average, rather higher yields than equivalent amounts of burnt lime, presumably because the limestones can be spread more evenly and incorporated more uniformly throughout the soil. In a few experiments on magnesian lime and limestones there was some evidence of greater benefit from the magnesian than from the high-calcium materials for sugar beet grown on recently reclaimed acid sands. Provided burnt lime or limestone are used at something approaching " lime requirement " rate, the form chosen and the precise rate of application are of little, if any, importance. After taking into account the cost of transport and spreading, the ease and uniformity of incorporation and allowing for the subsidy, farmers should select the form which supplies the desired neutralizing value (expressed as equivalent calcium oxide) at the lowest cost.

Soil Investigations

Soil organic matter

In continuing earlier work on the nitrogen complexes of soil organic matter, J. M. Bremner has studied the amino-acid composition of the protein material in various fractions and given some attention to the more chemically resistant fraction of the soil nitrogen. The main subject of investigation has, however, been the amino-sugar fraction, the presence of which was established by colour tests and chromatographic techniques. Six soils with nitrogen contents ranging from 0·17 per cent to 2·82 per cent were subjected to detailed examination for amino-sugars by various methods of analysis and it was found that from 6 per cent to 10 per cent of the total nitrogen was in the form of 2-amino sugars. K. Shaw investigated the decomposition of amino-sugars in the soil

by determining the amounts of ammonia-N and nitrate-N after incubating glucosamine and chitin with soil for various periods of time. After a slow start these materials nitrified readily, though less rapidly than casein or a nucleic acid preparation. After incubation for 35 days, 42 per cent and 54 per cent of the nitrogen added as chitin and glucosamine, respectively, were recovered as nitrate.

In earlier work J. M. Bremner could find no free amino-acids in cold aqueous extracts of several neutral clay loams and fen soils after concentrating the extracts at low temperature *in vacuo* and examining them by paper partition chromatography. More recently this technique revealed the presence of several amino compounds in aqueous extracts of acid peats, and serine, glycine, alanine, aspartic and glutamic acids could be identified. The amounts of free amino-acids detected were however very small and it does not appear likely that free amino-acids occur as more than traces in normal agricultural soils.

In conjunction with P. W. Arnold, of the School of Agriculture, Cambridge, and formerly of this department, J. M. Bremner investigated the possibility of applying paper chromatographic techniques to the separation, identification and estimation of various inositol phosphates, materials believed from work elsewhere to form a considerable fraction of the organic phosphorus in soils. The results so far obtained indicate that these techniques would be of limited value. Other methods of fractionating and characterizing inositol phosphates are being explored.

In continuing investigations, summarized on page 44 of the Rothamsted Report for 1951, on the reaction between lignin and nitrous acid, a need arose for a satisfactory method of separating and identifying small amounts of hydroxylamine. J. M. Bremner succeeded in devising a reliable method based on paper chromatography with acidic solvents and detection by specific reagents.

As a preliminary to a projected investigation on the rates of nitrification of various nitrogenous materials and on factors influencing the decomposition of plant residues in grassland soils, K. Shaw tested, and, in some cases, improved methods commonly employed in nitrification studies. Ammonia nitrogen in soil extracts prepared by a modification of Olsen's method, was determined by distillation with a buffer at pH 8·8, which did not appreciably decompose urea, glutamine, allantoin, asparagine and other labile compounds. Later work showed that distillation with magnesium oxide in a Conway microdiffusion unit at room temperature gave closely similar results to the buffer-distillation method. Glucosamine-nitrogen was recovered almost quantitatively as ammonia by the buffer-distillation method but no significant amount of ammonia was liberated from glucosamine by the magnesia-microdiffusion method. Amino-sugar nitrogen in soil hydrolysates could be estimated by the difference between these two methods.

Nitrates are being determined by the phenoldisulphonic acid method on an extract made with calcium sulphate solution. The determination of ammonia and nitrate nitrogen together by reducing with iron in acid solution at room temperature is being investigated but the results, so far, are not satisfactory.

Soil phosphorus

G. E. G. Mattingly carried out a number of pot and field experiments to gain experience of various techniques for using radiophosphorus as a tracer in studying the availability to plants of the phosphorus present in soils and fertilizers. In this kind of work it is necessary to establish that plant growth is not appreciably influenced by the radioactive tracer itself. If special precautions are taken to ensure that the ^{31}P and ^{32}P are uniformly distributed throughout an experimental batch of fertilizer, determinations of the radioactive form in any plant grown with this fertilizer will show how much of the ^{31}P as well as the ^{32}P came from the fertilizer. Plants will also take ^{31}P but not ^{32}P from the soil and it is thus possible to calculate for any prescribed set of conditions how far the fertilizer phophorus has been diluted by soil phosphorus. This amount of soil phosphorus may be taken as an estimate of " available " soil phosphorus and, following an American suggestion, is known as the " A value." It should be noted that the technique determines only an end-result and records only the historical fact that a certain proportion of the phosphorus in the plant had at one time been in the fertilizer, even though it may have reacted or exchanged with other phosphorus compounds in the soil and become " soil phosphorus " before it was taken up by the plant. In experiments on this subject the results obtained depend on the form of the test-fertilizer, the way in which it is applied to and incorporated with the soil, the pattern of root growth and many other factors, many of which must be examined experimentally.

Series of experiments were carried out with radishes and ryegrass on soils from three plots in the Exhaustion Land of Hoosfield, which had received no phosphorus in fertilizers or manures since differential manuring was discontinued in 1901. The radish experiment gave irregular results through poor germination. The ryegrass was cut three times. In the first cut superphosphate added after the soil had been crumbed gave slightly higher yields than superphosphate incorporated before the soil was crumbed, but this difference disappeared in the later cuts. Neither experiment showed any effect from varying the amounts of ^{32}P in the added superphosphate.

The results of the pot experiments, averaging several rates of added superphosphate, are given below together with typical recent results from a barley crop on the same plots.

Field treatment to 1901	Field results Barley 1950 cwt. grain per acre	Pot experiments g. dry matter per pot			
		Radishes		Ryegrass	
		no P	+ P	no P	+ P
no P	11·0	0·8	1·4	0·8	3·9
Farmyard manure ..	22·2	2·0	2·2	4·8	5·3
Superphosphate ..	20·9	1·6	1·9	4·4	5·1

The residues from superphosphate or farmyard manure applied over fifty years ago in the field gave somewhat higher yields in the pots than the average of the various rates of superphosphate added to the soil without manurial residues. The estimates of " available phosphorus " (A values) were 3 mg. P per 100 g. soil for the unmanured plot and 11 mg. P per 100 g. soil for the plots with residues

from superphosphate or farmyard manure applied last century. The radish and the ryegrass experiments gave closely concordant estimates of " A values."

Preliminary field experiments were carried out by G. E. G. Mattingly and G. W. Cooke to test the responses of beans, potatoes, fodder beet and swedes to four phosphate fertilizers, broadcast in advance of sowing, with a small dressing of radioactive superphosphate drilled with the seed on all plots. Determinations of total phosphorus and of the proportion derived from the placed superphosphate were made on several occasions throughout the season. On the average of three crops—potatoes, beet and swedes —at final harvest, the percentage of the plant phosphorus derived from the placed fertilizer were 8·5, 7·5 and 6·6 for superphosphate broadcast at the rates of 0, 0·3 and 0·6 cwt. P_2O_5 per acre. The " A values " derived from these data agreed satisfactorily with the amounts of superphosphate broadcast but the agreement may be fortuitous since some of the other fertilizers gave discordant results. The standard errors were high through the inevitable difficulties of working on small plots of isolated crops and using a very small experimental drill for placing the radioactive fertilizer and sowing the seeds. Radioactive fertilizers are much too expensive at present for full-scale experiments in the field and it will be necessary to refine the small-scale technique before tracers can be used to attack many problems of both theoretical and practical importance in crop nutrition and manuring. In this kind of work it is not sufficient to use radiotracers merely to demonstrate that water-soluble fertilizers placed near seeds are taken up by plants more rapidly than less soluble fertilizers in the same position or than broadcast fertilizers distributed throughout the whole mass of soil. Much detailed and exacting work will be needed before radiotracers can be used to resolve old problems and throw new light on mechanisms.

O. Talibudeen has used radiotracer techniques in studying the nature of the precipitated calcium phosphates which lie between dicalcium phosphate and hydroxyapatite. Suitable techniques were developed for measuring ^{45}Ca as oxalate and ^{32}P by the direct evaporation of aliquots. Attempts are being made to differentiate in precipitated calcium phosphates between primary nucleation, recrystallization and secondary nucleation of a heterogeneous phase from an apparently saturated solution. Using a light acid soil from Woburn and a heavy calcareous soil from Rothamsted, isotopic equilibrium measurements are being made to determine the percentage of the total phosphorus in equilibrium with the phosphorus extracted by acetate buffer solutions of different hydrogen ion concentrations and ionic strengths.

F. S. C. P. Kalpagé commenced an investigation into factors influencing the apparent solubility of phosphate rock and other fertilizers in the conventional citric acid and ammonium citrate tests for " available phosphoric acid."

Soil manganese

S. G. Heintze continued her investigations on the reduction and extraction of synthetic higher oxides of manganese added to alkaline soils, using various reducing agents. Hydroquinone followed by

calcium nitrate extracted little manganese from soils incubated with hausmannite or γ manganite and large proportions from soils treated with colloidal manganese dioxide, manganese sulphate or γ manganese dioxide. From a fen soil the recoveries were about three-quarters of those from mineral soil. Hydrosulphite in ammonium acetate extracted about one-half of the manganese added in any form to the mineral soil and about one-third of that added to the fen soil, apart from γ manganite which gave much lower recoveries from the fen soil. The proportions of the total manganese extracted from the untreated soils were roughly similar for the various extractants to those obtained from soils treated with colloidal manganese dioxide or manganese sulphate but were markedly different from those treated with hausmannite or γ manganite. From fen soil treated with colloidal manganese dioxide the proportion of added manganese extracted with alkaline pyrophosphate was low relative to that from the mineral soil or to the proportion of the total manganese extracted from untreated fen soil. It appears from this work that the inert manganese in some fen soils is not present in forms resembling hausmannite or γ manganite.

In a pot experiment with mineral soil treated with various manganese compounds, the manganese contents of the repeatedly cut Timothy grass fell off in the order: manganese sulphate (as crystals), synthetic γ manganese dioxide, synthetic hausmannite, synthetic γ manganite, natural pyrolusite and potassium permanganate (as crystals). The order for oxides reflects that obtained in reduction-extraction experiments.

General

E. M. Crowther, R. G. Warren, G. E. G. Mattingly and K. Shaw attended the Soil Fertility Meeting held in Dublin in July 1952 and organized by the Irish Department of Agriculture and Commissions II and IV of the International Society of Soil Science.

G. W. Cooke visited France, Belgium and the Netherlands with an Agricultural Research Council Travelling Grant to study recent developments in the production and testing of fertilizers based on dicalcium phosphate.

M. V. Jackson returned to the National Agricultural Advisory Service after secondment to this department for two years to gain experience in field experimentation. His place was taken by J. C. Wilcox. C. P. Kirkland of the Forestry Commission was seconded for a further year to assist in forest nursery investigations. J. K. R. Gasser, a Colonial Office Scholar spent part of the year in the Chemistry Department and part in the Pedology Department. W. B. Haines joined the department.

E. M. Crowther acted as Director of Studies for a week's course at Rothamsted on field experimentation, organized by the British Council and including lectures and demonstrations by members of the Botany, Chemistry and Statistics Departments, and the Field Experiments Section.

PEDOLOGY DEPARTMENT

A. Muir

At the invitation of the University of California Dr. D. M. C. MacEwan attended the meeting on clays and clay technology organized by Berkeley University during the summer. Mr. K. Norrish of the Commonwealth Scientific and Industrial Research Organization completed his studies on some Australian soils derived from basalt for which, together with some other work, he was awarded the degree of Ph.D. by London University. Mr. Norrish also carried out experimental work on the swelling of montmorillonite in salt solutions which is described below. Mr. Sant Singh of the Hindu University, Benares, has begun a study of some Indian black cotton soils, and Mr. J. Gasser has started some experiments on the behaviour of phosphate in soils under water logging conditions.

Mineralogical Studies

English soils

Little is known about the mineralogy of many of the sediments and surface deposits which give rise to the soils of this country. The opportunity has therefore been taken of examining a series of local soils in connection with a soil survey now being made in the Aylesbury district. The parent materials of the soils include Reading Beds, Clay-with-Flints, Brick-earths, and various sandy deposits (e.g. a pink sand from Ashridge and a red sandy clay from Whipsnade). The suites of minerals in all these deposits have been found to be similar, the main difference between the deposits being in the varying amounts of coarse and fine material. The chief "heavy minerals" present (in addition to iron ores) are zircon, rutile, tourmaline (brown, blue and violet varieties), kyanite, staurolite, garnet, green hornblende (rare) and andalusite (rare). The light fraction consists mainly of quartz. (I. Stephen).

African soils

The study of the soils from the Gold Coast (see 1951 Report) has been completed and will be published shortly. Further investigations have been carried out on soils from Tanganyika and the Equatorial Province of the Sudan.

In connection with a problem of poor sisal growth on an area of "gilgai" relief on the Athi Plains near Nairobi, Kenya, a number of Black Cotton Soil profiles has been examined. The general pattern of distribution of these soils, with their "island-like" relief is very like that found in Australia and elsewhere and it has been shown that the chemical and physical properties conform to the Australian results. The main soil consists of a heavy black clay, on which sisal growth is poor, with round islands of a browner and somewhat lighter-textured soil on which sisal grows well. Both kinds of soil are characterized by montmorillonite. The parent rocks of the Kenya gilgai soils are a series of incompletely differentiated volcanic rocks of Cretaceous to Recent age, among which phonolites and phonolitic trachytes are prominent. (I. Stephen, A. Muir).

Clay Mineral Studies

X-ray diffraction by inter-layer mixtures

Following on the work described in last year's report, a direct fourier-transform method has been elaborated for determining the proportions and types of components present in such mixtures, given the X-ray diffraction diagrams. This method has been tested in a few practical cases, and on the theoretical diffraction curves of Brown and MacEwan, and it appears to give reliable results, but further tests will be necessary.

The advantage of the new method is that it enables one to pass directly from the diffraction data to the composition, even in ternary and more complicated mixtures (though the more complicated the mixture, the greater is the chance of error). The "reverse" method, described in last year's report necessitates the preliminary calculation of the diffraction to be expected from a series of assumed compositions, and is thus hardly applicable to other than binary mixtures. (D. M. C. MacEwan).

Interlamellar swelling of clay minerals

A theoretical study has been made of the variation of attractive potential between charged sheets of montmorillonite, or similar lamellae, with separation, on the assumption that the following types of inter-layer force are active: (1) electrostatic attraction relayed between the negative sheets by the positive ions; (2) van der Waals' attraction; (3) "osmotic" repulsion due to the interlamellar ion clouds; (4) "adsorption" repulsion due to adsorbed layers of neutral molecules.

There are many uncertainties in any such calculations, particularly in the values assumed for the van der Waals' constant A, and the dielectric constant of the medium; but two conclusions emerge clearly from the calculations: (1) the electrostatic force can, in principle, be much more important than the van der Waals' force, if the cations are assumed to be "floating" between the sheets; (2) the electrostatic force will die away very rapidly with distance (approximately exponentially), so that at large separations (say $>$ 100 Å) it is likely to be negligible. (D. M. C. MacEwan).

The water sorption work described in the last Annual Report has been supplemented by X-ray work. The results have shown that interlamellar sorption of water on Na-montmorillonite occurs only if the resultant water concentration is greater than 3-4 H_2O/Na^+. This explains why Na-montmorillonite gives a single D.T.A. low temperature endothermic peak, whereas Li-montmorillonite gives a double peak. In the former case the water of hydration is squeezed out rapidly along with the remaining interlamellar water, whereas in the latter case differences of water mobility are allowed to develop. It has also been found that the results when combined with indirect heat data are best explained on the basis of a predominant electrostatic interaction between the silicate sheets and the interlayer ions. It can be concluded that the maximum interlayer ion concentration consistent with expanding properties of the mineral depends on the nature of the exchange ions and with Na^+ is about 160 m.e. per 100 g. This explains why Na-vermiculite with about 140 m.e. Na

expands with water whilst paragonite with 270 m.e. does not. It seems likely that the occurrence of considerable potassium fixation in soils is connected with this dependence of water sorption on the nature of the interlayer cation. The replacement of cations by K^+ might be expected to lead to a more complete exclusion of interlamellar water owing to its lower hydration energy. This water exclusion would tend to make cation exchange slower and lead to apparent fixation.

The sorption of pyridine and other similar ring compounds on montmorillonite has been studied by one-dimensional Fourier syntheses and spacing measurements. It has been found that these molecules are most commonly orientated with the plane of their rings perpendicular to the plane of the silicate sheets. This observation has enabled many different types of sorbed ring compounds to be distinguished merely by using spacing measurements. The possibility of utilizing montmorillonite both as concentrating agent for traces of organic compounds and as a method of identifying them *in situ* is under investigation. (R. Greene-Kelly).

Using a curved-quartz X-ray monochromator, a study has been made of the variation of *c*-axis spacing with salt concentration in a series of montmorillonite-water-salt systems. It has been possible to trace a definite *c*-axis spacing up to a value of rather above 100 Å. For the Na-montmorillonite+NaCl system, to take a typical example, the spacing increases up to about 20 Å as the concentration of salt is decreased; on further decreasing the concentration, a region of mixed spacings then occurs, followed by a markedly larger spacing, in the region of 35Å, which increases steadily to 100 Å (and perhaps further) on still further dilution. The whole process is reversible.

The spacing variation has been studied in more detail by the calculation of fourier transforms from microphotometer records of the X-ray diagrams. A considerable number of calculations have also been made on the effects to be expected from curvature, waviness, and lack of parallelism of the layers. The general conclusions which are as yet tentative, are that, in the high-spacing (> 30Å) complexes, (1) the layers are almost completely parallel; (2) the separation between them is very variable, the "spacing" determined from the X-ray data being an average effect; (3) the layers may be wavy, provided the angular deviations are small.

Polyvalent ions, Ca^{++} being typical, do not give the large spacings. H^+-clay in suspension in HCl solution shows an interesting effect, large spacings similar to those obtained with Na^+-NaCl systems being initially obtained, but reverting on standing to small spacings similar to those given by polyvalent ions. The tentative explanation of this is that it is due to the gradual release of Al^{+++}, or other polyvalent ions, from the clay at low pH values. (K. Norrish, D. M. C. MacEwan).

The results of dehydration tests on expanding minerals have confirmed the Hofmann and Klemen hypothesis (1950) that exchange ions of small radius, e.g. less than 0·8 Å, move into vacant octahedral sites on heating. Recent work has shown that it is also necessary that the charge on the silicate sheet originates from octahedral substitutions, otherwise no movement takes place. In

effect this means that montmorillonite is the only common mineral of the montmorillonoid group that shows this property. This work has been made the basis of a specific test for montmorillonite (23). The test has been applied to many of the clays previously investigated, and found to contain a dioctahedral montmorillonoid mineral, with the view of classifying them as montmorillonites or beidellites (nontronites). Several new problems concerning the weathering of soil parent materials to clays have arisen from this work and are under investigation. (R. Greene-Kelly).

Soil clay mineralogy

Lancashire boulder clays. Twenty samples from the lowest layers of soil profiles overlying drifts of Triassic, Carboniferous and mixed Trias-Carboniferous origin have been examined by X-ray diffraction. It is thought that the degree of disorder of the layers of the hydrous mica mineral commonly occurring in them may be a useful method of differentiating the Triassic from the Carboniferous drifts as soil parent materials. It seems that the hydrous micas in the Triassic drifts are less disordered than in the Carboniferous drifts, but the work is not complete. (G. Brown).

Soils from Cornwall. A study of the weathering of igneous and metamorphic rocks in the Lizard area, Cornwall, has been completed. Kaolin, illite and chlorite occurred in the clay ($<\cdot002$ mm.) separated from the weathered product immediately overlying granite (and derived from its biotite), and montmorillonoid and talc from that overlying the serpentine. (J. R. Butler).

An unidentified 14 *A mineral occurring in British soil clays.* In many of the soil clays from Britain which have been examined a mineral occurs which resembles chlorite in some respects and vermiculite in others, and may consist of interstratified chloritic and vermiculitic layers. It has not yet been possible to obtain the mineral in a pure state but careful work on its reaction to heat will probably establish its identity. (G. Brown).

Tropical soils. Many soil clays from Kenya, West Africa and India have been examined. It has been found that a 14 Å mineral resembling the unidentified mineral reported above occurs along with a montmorillonoid, kaolin and mica in some examples of black cotton soil from India. (A. Muir, G. Brown).

Australian soils. The results of a study of a series of black and red soils on basalt from the Lismore district suggest that the trend in each soil is towards the formation of minerals low in silica and it seems probable that the red soils may represent a more advanced stage of weathering than the black. Nontronite occurs in the parent rock and may be an important factor in maintaining the black soil stage where the direct change from rock to lateritic material would have been expected. (K. Norrish).

Grey wooded soils. An examination of the clay mineralogy of some grey wooded soils from Alberta and Saskatchewan showed that montmorillonoids, a 14 Å mineral, hydrous mica, kaolin, quartz and calcite occur. Interesting features about these soils are that there is an apparent synthesis of a 14Å mineral in the B horizon and that the montmorillonoid of the parent material differs from the

montmorillonoid in the surface layers. This suggests re-crystallization of the clay material.

Lepidocrocite. This mineral has been shown to occur in gleyed soils in Anglesey and Lancashire, and it is probably the pigment responsible for the orange mottling which occurs in these soils. An account of this work will appear in a forthcoming number of the Journal of Soil Science. Arising out of this work an attempt at the quantitative estimation of the lepidocrocite present is being made.

During the year techniques have been devised which enable X-ray examination of the clay from amounts of soil considerably less than 0·5 grams and if the need arose the amount required could easily be reduced ten-fold. This enables the clay from separate small segregations to be readily examined. (G. Brown).

Geochemistry

Distribution of trace elements in rocks and soils

A general survey of the distribution of trace elements in soils of England and Wales has started with a study of several Lancashire soil profiles. The four parent materials derived from Carboniferous and Triassic rock materials carrying soils with drainage conditions ranging from free to very poor have similar concentrations of Ba, Cr, Ga, Li, Ni, Rb, Sr and V but significantly different concentrations of Mn and Zr. From the parent material to the surface soil the concentration of most elements (based on the oven-dry weight) decreases irrespective of drainage conditions, e.g. Cr, Li and Rb; the concentration of Mn varies irregularly in the profiles and those of Pb and Sn increase markedly towards the surface, for example, reaching 160 p.p.m. Pb and 40 p.p.m. Sn compared with 25 p.p.m. and 4 p.p.m. respectively at depth. (J. R. Butler).

The association of the Teart pastures of Somerset with certain beds of the Lower Lias formation is now well-known, and *a priori* it would be expected that other dark clays and shales would be high in molybdenum. Investigations are proceeding on the distribution of certain trace elements in sedimentary rocks, with particular reference to the Lower Lias deposits, as a step towards an understanding of their distribution in soils derived from these formations. This work has been much facilitated by the co-operation of the Geological Survey who have kindly supplied samples from a deep boring at Northleach. The Lias deposits are also being studied at their outcrop on the Dorset coast.

Variations have been found in the molybdenum content of these deposits ranging from well below 10 to over 100 p.p.m. The evidence so far suggests that the high Mo concentrations are confined to the shaly deposits in the lower zones of the Lower Lias, there being little in the limestone bands or the higher zones. It is intended also to study the Mo distribution in shaly deposits from other formations to see whether, in fact, these high concentrations are peculiar to the Lower Lias, or are of more general occurrence. (H. H. LeRiche).

In connection with the study of the Cornwall soils reported above it was found that the trace element content of the rocks

differed considerably as would be expected from their different mineralogical compositions, and on weathering to clay there is evidence for a slight loss of gallium with respect to aluminium; similarly the ratio K/Rb changes in favour of K, the larger ionic radius of rubidium facilitating its preferential removal since it cannot be held tightly by the clay minerals. (J. R. Butler).

Spectrographic Work

The high dispersion glass spectrograph (constructed by Professor Mannkopff of Göttingen, whilst at Rothamsted) has proved highly suitable for studying the complex arc spectra of the rare earths. The relatively common members of the group, Sc, Yt, La, Ce, Pr, Nd, Gd, and Dy, can be estimated in a natural mixture of the rare earth oxides by using the very stable line pairs given by most of the possible pairs of elements. Samarium (a fairly common rare earth) volatilizes in the arc conspicuously before the other elements mentioned above and preliminary tests indicate that barium may be a suitable internal standard.

The determination of Ba, Li, Rb and Sr in soils and other solid specimens is now on a routine basis by using Cr, Sm and Cs as internal standards for Sr, Ba and the alkalis respectively. The minimum number of spectrograms (resulting from separate burns of the specimens) required to estimate the elements Ba, Be, B, Cs, Cr, Co, Cu, F, Ga, Ge, In, La, Rb, Li, Mo, Mn, Ni, Rb, Ag, Sr, Tl, Sn, V, Yt, and Zr, is now five. (J. R. Butler).

Gleying of Soils

Continuing the investigation of the movement of sesquioxides in the soil, attention has been concentrated on the properties of the debris of various species of conifers with respect to the mobilization of iron and aluminium in forest soils. It has been found that, for some ten different species, sterile water extracts of the undecomposed leaves or needles will dissolve ferric and aluminium oxides, with reduction of the former to the ferrous state. The effect has been investigated over the pH range of 4-7·5, and it has been found that both solution and reduction take place even under conditions at once alkaline and aerobic. While the extent of the solution and reduction is decreased by aeration or by raising the pH, the degree to which these factors influence the reaction varies considerably for the different species.

In the case of Scots pine it has been possible to show that the ferrous compounds formed by reaction with ferric oxide are organic complexes which possess great stability under oxidizing and alkaline conditions. The dissolved aluminium appears to be present in the form of an organic complex of comparatively low stability.

A number of deciduous and other types has also been investigated. In this group it has been found that, while the same type of solution-reduction reaction takes place, the variation between species is much greater than in the case of the conifers. Thus heather is active in mobilizing iron at pH values in the region of 4·5, i.e. the untreated water extract, both under aerobic and anaerobic conditions; if, however, the pH of the extract is previously raised to 7, the activity falls to a comparatively negligible value. In

contrast, a water extract of aspen leaves is very active in mobilizing the sesquioxides under anaerobic conditions, even at the high pH values, although its activity is markedly decreased by the presence of air. This latter observation is of interest in connection with the " Bluff Podzols " and grey wooded soils of central Canada and similar soils in the Soviet Union which occur in part under aspen. Thsee soils are podzolic in character, but may have pH values up to or above 7. Thus far, the laboratory findings have been in keeping with the field evidence. In the case of autumn-fallen ash leaves, however, the aqueous extract is a fairly efficient mobilizer of iron, and, although its effectiveness is considerably reduced by raising the pH of the reaction mixture, the residual effect is still appreciable. Since the ash is not known to be a podzol-forming species, it is apparent that an additional factor must be involved. Possibly the soil micro-fauna are responsible for counteracting the leaching action of the ash and similar non-podzolizing species. (C. Bloomfield).

SOIL MICROBIOLOGY DEPARTMENT

H. G. THORNTON

During the year under review the permanent scientific staff of the department has been increased by the appointment of E. R. Turner to carry out research on biochemical problems connected with the infection of leguminous plants by nodule bacteria. S. M. Bromfield returned to Melbourne after the completion of two years' studies on the microbiology of reduction processes in soils, for which he was awarded the degree of Ph.D. of London University. J. Meiklejohn left in June for Kenya in a year's secondment by the Colonial office to survey and report on problems of soil microbiology in East Africa.

The work of the department has followed the main course shown in previous reports. The work has dealt with the soil micro-population as a whole and with some of its component organisms, and a special section of it has again been devoted to the nodules of leguminous plants.

PARTIAL STERILIZATION OF SOIL IN THE FIELD

The study of the changes in soil population induced by the application of formalin to the soil of Sitka spruce nursery beds was continued by L. M. Crump. The plots sampled were laid out by the Chemistry Department and those studied comprised control plots without formalin (OO) and plots dosed respectively with formalin in March 1951 only (FO), in March 1952 only (OF), and in March 1951 and March 1952 (FF). Formalin applied this year caused an initial depression in bacterial numbers found by plating on a medium allowing a variety of nutritional groups to develop. This was followed by a rapid rise to numbers two to three times those on the untreated plot. These high numbers were maintained until May, after which the numbers fell to the control level. In this year's experiment bacterial numbers in the treated plots showed a smaller and less persistent rise than in previous years. This may have been due to weather or to the fact that a smaller dose of formalin was applied. Platings on special media showed that the quality of the microflora was also altered by formalin applied this year, which encouraged the development of organisms tolerant to formalin, of nitrate reducers and, in the early samplings of gelatin liquefying organisms, mostly spore-formers. The residual effect of formalin applied in 1951 (FO plots) showed to a small extent in the platings on the generalized medium and also in the numbers of nitrate-reducing organisms.

The numbers of amoebae in Ampthill soils following partial sterilization with steam and with formalin were estimated by B. N. Singh in samples taken in successive samplings over a period of 3 years. In plots treated with formalin, numbers of amoebae were lower, but in steam-treated plots higher than in the untreated plots sampled, although partial sterilization by both methods increased the numbers of bacteria. It is suggested that these effects may be due to changes in the food value to amoebae of the bacterial population as a result of the two treatments.

Competition between Actinomycetes & Root Disease Fungi

Practical results in the biological control of root diseases by competitive micro-organisms will be more probable when more is known as to the various processes of competition and the effects on these of environment. Attention has usually been centred on the action of antibiotic secretions produced by the antagonist. But the results obtained by F. A. Skinner in his continued investigation of the competition between the antibiotic producing actinomycete, *Streptomyces albidoflavus*, and the root pathogenic fungus *Fusarium culmorum*, make it clear that the actinomycete can affect the fungus in three ways, (1) by direct attack on the fungal hyphae, (2) by the production of antibiotic secretions and (3) by competition for nutrients. He has shown that soil colloids and certain organic materials will prevent or reduce antibiotic activity of the actinomycetes and particularly that a very low concentration of bentonite will completely remove the antibiotic activity of a filtrate of an actinomycete culture and that bentonite will also prevent direct attack by the actinomycete on the fungus. The addition of bentonite to mixed cultures thus affords a means of examining competiton for nutrients, by removing the other two methods by which the actinomycete can check the fungus. When the two organisms were grown together in sand moistened with a medium containing 1 per cent glucose, growth of the fungus was completely inhibited. With the further addition of sufficient bentonite to adsorb the antibiotic secretions, fungal growth was still reduced by the actinomycete as compared with a pure culture of the Fusarium. This reduction is ascribed to competition for nutrients. In sand with a medium containing only 100 p.p.m. of glucose the actinomycete still produced some reduction in growth of the fungus, but in this case the further addition of excess bentonite produced a negligible effect. Thus at a low nutrient level, antagonism is almost wholly due to competition for nutrients. In soil culture also the actinomycete produces some reduction in growth of the fungus and this again appears to be due to competition for nutrients since it is not affected by the addition of bentonite. This work thus emphasizes the importance in soil of competition between micro-organisms for nutrients even when dealing with an antagonist capable, under the right conditions, of producing antibiotic secretions. The cultures grown in media with bentonite also showed that this competition for nutrients was more acute at high than at low nutrient levels. This work is now being written for publication.

Decomposition of Aromatic Compounds in Soil

The use of a variety of aromatic halogen compounds in soil makes it of importance to know what effect micro-organisms have on them. Practically nothing is known about the bacterial decomposition of such compounds.

Previous work at Rothamsted by F. Tattersfield showed that α-chloronaphthalene was susceptible to attack by soil bacteria, and P. H. H. Gray and H. G. Thornton isolated several strains of bacteria which could utilize naphthalene as sole carbon source. Consequently, work on the mode of breakdown by bacteria of

naphthalene and α-chloronaphthalene was started by N. Walker. G. H. Wiltshire of the Biochemistry Department has collaborated in this work. Three strains of bacteria have been isolated and their action on naphthalene and α-chloronaphthalene has been studied. The first oxidation product of naphthalene is *d-trans*-1:2-dihydro-1:2-dihydroxynaphthalene which is further decomposed via salicylic acid and catechol. These compounds have been isolated from culture filtrates and also shown to be oxidized enzymatically by washed naphthalene-grown cells. The metabolism of α-chloronaphthalene appears to proceed in an analagous manner through a chlorodihydro-dihydroxynaphthalene and 3-chlorosalicylic acid. α-bromonaphthalene is also attacked by these bacteria and so far the only intermediate detected is an acidic substance which behaves like a bromosalicylic acid. Further work on the other intermediates involved in the bacterial decomposition of naphthalene and chloro- and bromo-naphthalene is in progress.

N. Walker has also studied, in collaboration with Professor W. C. Evans of Bangor, the decomposition by soil bacteria of *o* and *m*-hydroxybenzoic acids. There was evidence that the former compound, salicylic acid, now found to be a decomposition product of naphthalene, was oxidized via catechol, the subsequent path of decomposition being known, and that meta hydroxybenzoic acid was oxidized via gentisic acid, the further stages being still unknown.

Reduction Processes in Soil

S. M. Bromfield completed his work here on the reduction of sulphates and of ferric oxide in soil and by isolated pure cultures. This work on sulphate reduction in soil treated with carbon tetrachloride is of special interest because he has identified some of the organisms that inhibit reduction in untreated soil and which are inhibited by the partial sterilizing agent. He summarizes the results of his work as follows:—

Sulphate reduction in soil treated with carbon tetrachloride

A study was made of the reduction of sulphate to sulphide in soil treated with carbon tetrachloride. Hydrogen sulphide was evolved from such soil when moistened with sucrose and ammonium sulphate solution and incubated aerobically. Hydrogen sulphide formation took place in such a system with soil moistures less than field capacity and over a pH range of 5 to 8.

The organism responsible was isolated and identified as *Bacillus megatherium*. Several strains of this organism reduced sulphate in well-aerated sterile soil but not in soil incubated anaerobically or in liquid media.

The action of carbon tetrachloride in fresh soil is to check or destroy certain fungi and bacteria which normally inhibit sulphate reduction by *Bacillus megatherium*. Some of these organisms were isolated and shown to be sensitive to carbon tetrachloride and to inhibit sulphate reduction by *Bacillus megatherium* in sterilized soil. The isolates did not inhibit growth of this organism on synthetic media.

The reduction of ferric compounds by Bacillus Circulans *and other bacteria*

Bacteria that could reduce ferric compounds in various media were isolated from soil and grass and were identified. Their activity differed greatly and the most active species, *Bacillus circulans*, isolated from soil was selected for further study.

Growing cultures of this organism reduced ferric compounds in liquid media kept under anaerobic conditions, with the formation of soluble and insoluble ferrous compounds.

Reduction of ferric hydroxide also occurred in liquid cultures exposed to air but here the amount of ferrous iron in solution decreased as the surface area was increased.

Neither the supernatant from centrifuged cultures nor cultures autoclaved or treated with chloroform would dissolve or reduce ferric hydroxide.

The organism was, however, unable to derive oxygen needed for its growth from ferric oxide under anaerobic conditions but where another compound containing available oxygen was supplied ferric oxide or phosphate were readily reduced.

Washed cells of the organism reduced ferric iron in the presence of certain hydrogen donors in whose presence they could also reduce methylene blue.

Treatment of the washed cells with dehydrogenase inhibitors prevented iron reduction.

Iron-reducing bacteria were found in the surface layers of gleyed soil but not in samples taken at a depth of 10 feet.

Nitrifying Bacteria

J. Meiklejohn has continued her study of the mineral requirements of Nitrosomonas and Nitrobacter which has formed the subject of publications.

Soil Protozoa and Myxobacteria

L. M. Crump has continued her work in the excystment of soil amoebae. She has also commenced a study of the soil amoebae that feeds on the potato root eelworm, isolated in Holland by Drs. A. P. Weber, L. O. Zwillenberg and P. A. Van der Laan.

B. N. Singh continued his taxonomic studies of soil amoebae continuing his work published in the Philosophical Transactions of the Royal Society, and has investigated the life history of the Myxobacterian organism Mellitangium, isolated from Rothamsted soil.

Investigations of Nodule Bacteria, Rhizobium and Leguminous Plants

Inheritance in clover of factors affecting nodule activity

Experiments were continued by P. S. Nutman on the inheritance in clover of factors determining the effectiveness of the plant's response and the relation between host controlled and bacterial strain controlled variation. These will be reported at a later stage.

Influence of root secretions on nodule formation

Further work has been undertaken by P. S. Nutman on the inhibitory and stimulatory effects of root secretions on nodule formation on plants growing nearby. To examine further the hypothesis that both effects may be due to the same substance acting at different concentration levels, an examination was made of nodulation in an agar medium in which other plants had previously been grown (preplanting). The quantity of root secretion supplied to the agar was regulated by varying (1) the number of preplantings, (2) the duration of preplanting and (3) the species or variety of plant used for preplanting. As it was known that hereditarily early or late nodulating lines of clover differ from each other and from lucerne, these three kinds of plant were used in both preplanting and in testing for stimulation or inhibition.

The results were as follows:—(1) With all combinations of preplanted and tested plants an initial increase in nodule numbers followed a short period of preplanting (15-20 days); (2) on clover following an initial stimulation, inhibition (i.e. reduction in number of nodules) increased linearly with increasing periods (up to 80 days) and with the number of preplantings by each plant type; (3) inhibition in clover was greatest in sets preplanted with lucerne and least with late-nodulating clover; (4) no difference in inhibition was observed between early- and late-nodulating lines *as test plants*; (5) in contrast to clover, lucerne inhibition was independent of the duration of preplanting beyond about 15 days, or of number of preplantings or type of plant used in preplanting.

From these results the following conclusions were drawn: (1) the level of root secretion required for stimulation (i.e. for nodule initiation) is reached at an early stage in seedlings of all kinds; (2) the clover nodule inhibitory substance is produced at a constant rate by the root; (3) the lucerne nodule inhibitory substance reaches full active concentration within 2-3 weeks of sowing. These experiments demonstrate concentration effects but do not allow firm conclusions to be drawn about the number of different substances concerned. They are not, however, at variance with the single substance hypothesis, such a substance being produced more copiously by lucerne than by clover and more by early nodulating than late nodulating lines of clover, and acting as a general stimulating agent at low concentrations and at higher concentrations inhibiting nodule development, progressively with increasing concentration for clover but having a maximum effect at a relatively low concentration for lucerne. This substance is evidently quite stable in agar culture.

A further interesting result in this experiment was the regular stimulation of clover nodulation by preplanting whereas it was previously shown, in contrast to lucerne, that clover plants planted together in the same tube, instead of successively as above, do not mutually stimulate earlier nodulation. This may be due to a preliminary activation of the primary root secretion by the nodule bacteria in the rhizosphere, this process taking place more slowly in the clover root environment.

The formation of coloured substances in the neighbourhood of roots growing in bentonite

In the course of the work on root secretions it was noticed that when clover and some other plants were grown in bentonite, a coloured zone appeared in the neighbourhood of the roots. There was circumstantial evidence suggesting a possible connection between this phenomenon and the active secretions. It has therefore been further studied by P. S. Nutman in collaboration with E. R. Turner.

Preliminary results include the effect of pretreatment of the bentonite and survey of the effect of different mineral structures. Comparison was made of Ca, K, and Na treated bentonite, all of which gave colour production, whilst bentonite treated with sugars showed greatly reduced colour production. This latter effect may be due to the expansion and blocking of the crystal lattice. Previous work on the colour production by clays has suggested that it is due to interlamellar adsorption followed by oxidation, which may involve iron. Therefore other types of crystal lattice and composition have been investigated viz:—hectorite (a montmorillonite with magnesium in place of aluminium), mica and a sample of bentonite treated with lithium kindly supplied by the Pedology Department. This bentonite does not expand in water. No colour was produced with mica. Lithium-treated bentonite gave normal colour production whilst hectorite showed reduced colour production. Other minerals will be investigated but these preliminary results suggest that expansion of the crystal lattice is not essential for colour production but the possibility of iron being involved in the reaction is not excluded. Attempts are being made to elute the coloured material from the bentonite.

The growth of Rhizobium in the clover rhizosphere

Investigation by H. Purchase of the numbers of Rhizobium attained in pure culture in the immediate neighbourhood of red clover roots in controlled tube experiments has revealed that a population of 10^8–10^9 bacteria per ml. of medium is quickly attained and is maintained steadily for some weeks. This population is far in excess of the number required for maximum nodulation, shown by other (preliminary) studies to be between 2×10^3 and 2×10^5 per ml. Some plant lines selected by P. S. Nutman bear greater or fewer nodules than the commercial strain or are completely resistant to infection, but they all support a similar population of Rhizobium in their root surroundings.

The number of virulent rhizobia near the roots can be maintained at a low level when non-virulent rhizobia (i.e. a strain incapable of infecting the host plant) are present. This effect may well operate in the field, for example when one legume crop is succeeded by a legume from a different cross-inoculation group. The size of the inoculum for the second crop may thus well be critical for nodule establishment under such conditions.

Roots of plants growing on agar medium could not be shown to exert any chemotactic effect on rhizobia over as short a distance as 3 mms. Direct inoculation of a root growing on agar results in a spreading of the rhizobia along the root, usually in a narrow band

about 1—2 mms. on each side of the root. That the prime cause of the spreading may be mechanical is tentatively suggested by the observation that a glass capillary tube, similarly inoculated, also develops a zone of rhizobial growth along its entire surface.

Rhizobium bacteriophage

Work on inhibiting effects on phage multiplication by crystalline pancreatic ribonuclease and by crystalline chymotrypsin has been started. Neither of the two enzymes has any direct effect on phage particles, but if added to liquid bacterial cultures which are then infected with bacteriophage, they inhibit multiplication of bacteriophage. Ribonuclease added to a concentration of 0·1 per cent completely inhibits phage multiplication for about 3 hours after which the multiplication begins and eventually proceeds at a rate comparable to that taking place in the absence of the enzyme.

Chymotrypsin at a concentration of 0·01 per cent completely inhibits phage multiplication for 2–3 days after which it starts to multiply and eventually the phage concentration reaches that of a control. At a concentration of 0·1 per cent, chymotrypsin seems to inhibit phage multiplication permanently.

Concentration of active phage falls in the presence of both host bacteria and chymotrypsin, whereas chymotrypsin alone has no such effect. This phenomenon is not encountered with ribonuclease, whose presence together with host bacteria does not lead to any appreciable drop in the concentration of active phage.

Host bacteria are affected by chymotrypsin: this is evident from the fact that formation of motile forms is prevented, and the ability to form colonies on agar medium without chymotrypsin is decreased, although the rate of multiplication in liquid media (where chymotrypsin was present) measured by means of haemocytometer counts, does not seem to be affected. This work was carried out by J. Kleczkowska in collaboration with A. Kleczkowski of the Plant Pathology Department.

BOTANY DEPARTMENT

D. J. Watson

Miss G. N. Thorne was awarded a Ph.D. degree of the University of London.

Plant Nutrition

Micronutrients (K. Warington)

Work in the previous year (1951 Report, p. 62) showed that low concentrations of vanadium partially counteract the development of iron deficiency chlorosis induced by excess manganese, though higher concentrations are toxic and eventually cause chlorosis in presence of non-toxic concentrations of manganese. In the early stages of growth, vanadium-treated plants have dark green leaves and stunted shoots suggesting a high-iron, low phosphorus status. Experiments were therefore made with soybean and flax to see (1) whether vanadium increases iron uptake, or reduces phosphorus uptake and (2) whether the effects of vanadium depend on the supply of iron and phosphorus in the culture solution. Injurious effects of vanadium appeared first in the root; when they were slight the only symptom was thickening of the root tips, but high concentrations of vanadium almost suppressed the growth of lateral roots. In the leaves, temporary deepening of the green colour generally occurred, followed by chlorosis and a marked reduction in size. Both 2·5 p.p.m. and 5 p.p.m. V were always toxic, but the symptoms were less severe and developed more slowly with increase in iron supply from 3 to 10 p.p.m.; 0·5 p.p.m. V was harmful when only 3 p.p.m. Fe were given, but not at higher rates of iron supply. Phosphorus supply had less effect on the responses to vanadium, possibly because it was not varied over a wide enough range.

In another experiment on peas a still higher level of iron (20 p.p.m.) was tested, and the low phosphorus supply was reduced from 37 to 11 p.p.m. The toxicity of vanadium was greatly reduced by 20 p.p.m. Fe and there was some indication that it increased at the lower phosphorus level. Chemical and spectrographic analyses will be made on the material from these experiments to determine how the vanadium treatments affected uptake of iron and phosphorus.

An attempt was made to compare the effects of vanadium on iron deficiency induced by excess manganese with that caused by low iron supply in the nutrient solution. As high vanadium supply greatly restricts root growth, the vanadium treatments were withheld until the plants had grown adequate root systems, so as to avoid confusing a direct effect of vanadium on iron uptake with a possible indirect effect due to a reduction in the absorbing surface of the root. Neither 5 nor 0·5 p.p.m. V had any counteracting influence on established symptoms of manganese excess. The results for the low-iron plants were inconclusive, because the chlorosis appeared erratically; the higher rate of vanadium reduced plant dry weight at both high and low levels of iron supply.

In other experiments, the effects of excess manganese and molybdenum were compared with that of vanadium in similar conditions of varying iron supply, but the results are not yet available.

Nutrient uptake by roots (E. C. Humphries)

It has previously been established (1951 Report, p. 63) that the rates of uptake of nitrogen, phosphorus and potassium by excised barley roots increase with increase in the concentration of sugars present in the roots. Further work has now shown that the rate of uptake depends on the reducing sugar content, and that the sucrose content has little or no effect. Whether glucose and fructose, the main components of the reducing sugar fraction, are both concerned in the absorption process, and the nature of the mechanism involved, are not known. It is unlikely that sugar merely provides energy for accumulation of salts against a concentration gradient, as this would require only very small amounts of sugar.

Experiments by other workers on the bacterium *Escherichia coli* have suggested that uptake of potassium occurs through formation of the potassium salt of a hexose phosphate. If such a mechanism were responsible for potassium absorption by roots, it would be expected that the rate of uptake of potassium would depend on the phosphorus content of the roots, when this is low. Excised roots from barley plants grown with a deficiency of phosphorus were supplied with potassium either as chloride or as phosphate. Phosphorus was absorbed from the K_2HPO_4 solution and the organic phosphorus content of the roots increased, but the rate of uptake of potassium was no greater than that from the KCl solution which did not change the organic phosphorus content. These results do not support the hypothesis that hexose phosphate is concerned in potassium uptake, but it is possible that, although the roots were taken from plants showing severe phosphorus deficiency symptoms, the hexose phosphate content was still not sufficiently low to limit potassium uptake, or else that, although the organic phosphorus content increased when phosphate was supplied to the roots, there was no increase in hexose phosphate.

Uptake of nutrients from solution sprayed on leaves (G. N. Thorne and D. J. Watson)

Chemical analyses of material from the experiment in which leaves of sugar beet grown in soil were sprayed with solutions supplying nitrogen, phosphorus and potassium separately and in all combinations (1951 Report, p. 63) were completed. They showed that uptake of a nutrient from the spray, as measured by the difference in nutrient content between plants that received the nutrient in the spray and those that did not, was the same whether or not other nutrients were present in the spray. However, uptake of a nutrient from the soil was affected by absorption of other nutrients through the leaves; this occurred when the nutrients absorbed by the leaves caused increased growth. Thus, plants sprayed with a solution supplying nitrogen alone grew larger and took up more phosphorus and potassium from the soil than plants

sprayed with water. Similarly, spraying with solutions supplying potassium but no phosphorus caused increased absorption of phosphorus by the roots.

The increased nutrient content of sprayed plants accounted for about 50 per cent of the nitrogen and potassium and 20 per cent of the phosphorus supplied in the spray solutions. The recoveries of nutrients applied to the soil, determined from the differences in composition between plants with and without a complete fertilizer dressing, were 20 per cent for nitrogen, 10 per cent for phosphorus and 30 per cent for potassium, so that, as in earlier experiments, the apparent recovery in the plant of nutrients applied to the leaves was about twice as great as that of nutrients applied to the soil.

An experiment on sugar beet was made to find out whether nutrient uptake from solutions sprayed on leaves, and its effects on growth, depend on the level of nutrient supply to the roots. The plants were grown without fertilizer, or with N, P and K applied to the soil at sowing, singly and in all combinations. They were sprayed daily with water or with solutions supplying N, P or K separately. The nutrients supplied in the sprays all caused increases in dry weight, and the increases were smaller when the nutrient in the spray was also applied as fertilizer to the soil. Data on the effects on nutrient content of the plants are not yet available. This experiment should provide more reliable comparisons of the efficiency of nutrient uptake from the soil and through the leaves than previous ones, in which recovery from the soil could be calculated only for complete fertilizer dressings.

Tomato plants grown with two levels of fertilizer applied to the soil, and sprayed either with water or a complete nutrient solution, showed no response in yield to the nutrient spray, although the fertilizer application caused a large increase in yield. This confirms a previous experiment (1951 Report, p. 63) which also showed that although spraying with the nutrient solution did not affect yield, it increased the nitrogen and potassium contents of the plants. Whether nutrient uptake from the spray occurred in the 1952 experiment is not yet known.

The possibility of increasing the protein content of sugar beet tops by spraying the leaves with a solution of a nitrogenous fertilizer (1951 Report, p. 65) was further investigated in a field experiment, in collaboration with the Biochemistry Department. Solutions of ammonium nitrate (3 per cent) and urea (2·3 per cent) supplying equal amounts of nitrogen were used and gave similar results. On one series of plots the leaves were sprayed on six occasions in late September and on another series the same volume of solution was applied on the same occasions to the soil between the rows of plants. At harvest in mid-October both treatments had increased the dry weight of leaf lamina and the nitrogen content of all parts of the plant, and the increases from spray applied to the leaves were always greater than from spray applied to the soil. Spraying the leaves doubled their protein yield, and about 30 per cent of the nitrogen applied was converted into protein. Spraying the soil increased the yield of protein in the leaves by 60 per cent, and only 15 per cent of the nitrogen applied was recovered as leaf protein. These results confirmed those of the previous year's experiment

and also showed that application in solution to the leaves was much more effective than application to the soil. In both experiments, the percentage of sugar in the roots was slightly reduced by the spraying treatments, but there was no significant reduction in yield of sugar per acre.

The leaf area of a wheat crop in the field reaches its maximum towards the end of May, and decreases steadily throughout June and July. This is the time when climatic conditions are most favourable for photosynthesis, so that if the fall could be delayed, yield might be appreciably increased. The senescence of leaves that leads to decline in leaf area is associated with transport of nutrients to the developing ears, so it seemed possible that the life of leaves might be prolonged, and leaf area increased during June and July, by spraying them with nutrient solutions at about the time of maximum leaf area. This was tested in a field experiment in which spraying the leaves with ammonium nitrate on eight occasions in May and June was compared with spraying the same solution on the ground at the same times, and with the same quantity of nitrogen applied as a top-dressing of " Nitro-chalk " in April. In June and July, the leaf area of the sprayed plants was slightly greater than that of the controls without nitrogen, but was no greater than that of plants which received the top-dressing. No significant differences in grain yield between the three methods of nitrogen application were found, but the top-dressing caused a larger increase in straw yield. The recovery of nitrogen from the solution sprayed on the leaves was only slightly higher than that from the application to the soil at the same time. The top-dressing had caused a large increase in leaf area in April and May and it may be, therefore, that spraying in May and June would be more effective if the crops had previously received a top-dressing, and it is intended to test this in 1953.

Potassic fertilizers are said to be ineffective on old stands of lucerne because the plants are so deeply rooted that they are unable to take up potash from the surface layers of the soil, and it has been suggested that better utilization of potassic fertilizers might be secured by spraying them in solution on the leaves. A field experiment was made to test this. On some plots, potassium sulphate at the rate of 120 lb. per acre was applied in a solution sprayed on the leaves on three occasions before each of two cuts; other plots received at the same times the same amount of potash sprayed on the soil between the plants. The treatments had no effect on yield, and information on their effects on potash uptake is not yet available.

Biology of Wild Oats

(J. M. Thurston)

Germination and dormancy

Of the 2,000 seeds of *Avena ludoviciana* fed to a calf (1951 Report, p. 67), three more germinated in the mixed dung and peat bedding kept for a second year in a moist condition in trays in the glasshouse, bringing the total number of seeds that remained viable after passage through the animal to only 10.

A previous experiment (1951 Report, p. 67) showed that more wild oat seeds germinated in the first season but many fewer in the second season when sown in farmyard manure than when sown in soil. An experiment was started in September on recently harvested seed of *A. fatua* and *A. ludoviciana* to compare the effects on germination of other organic materials, (sewage sludge, straw compost, fresh grass-mowings and peat) with those of farmyard manure. To see whether variation in organic matter content of soil affects germination, seeds were also sown in a range of soils from Barnfield, taken from plots that have received no manure, mineral fertilizers only, rape cake or farmyard manure annually for many years. Barnfield was chosen because it is free of wild oats. Seeds were also sown in sand or in a sandy heath soil for comparison with the heavy loam of Barnfield.

By the end of November, few seeds of *A. fatua* had germinated, presumably because the peak germination period for this species does not occur until Spring. Over 75 per cent of *A. ludoviciana* seeds sown in peat, and 60 per cent of seeds sown in sand had germinated, but for all the other treatments germination was below 50 per cent, ranging from 25 per cent to 45 per cent for the soils, and from 1 per cent to 35 per cent for the organic materials. These results indicate that initially the percentage of dormant seeds was low, but that dormancy was induced by sowing in soil, and to a greater extent by the organic materials (except peat). A similar, though smaller, induction of dormancy by farmyard manure occurred in the first two months of the previous experiment, and it remains to be seen whether, as before, the dormancy will be less persistent in the seeds sown in the organic materials.

Observations were continued on the plots of the field experiment sown with wild oats at different depths in October, 1950, and subsequently receiving varied cultivation treatments (1951 Report, p. 68). More seedlings of *A. fatua*, but fewer of *A. ludoviciana* appeared in the second year than in the first. More seeds of both species germinated on shallow-sown than on deep-sown plots; this repeated the first year's results for *A. fatua*, but was the opposite of that found for *A. ludoviciana*. Shallow-sown plots that were frequently harrowed produced fewer seedlings than those left undisturbed through the summer; this may be partly due to destruction of some of the young seedlings by the harrow before they emerged. Neither autumn nor spring ploughing of the deep-sown plots had any appreciable effect on germination of either species. About 80 per cent of the seeds sown have not yet produced seedlings, even with the treatments that gave the highest germination.

Variability within the species, and the diagnostic value of seed characters.

Avena fatua and *A. ludoviciana* are distinguished primarily by morphological characters of the spikelet, for they differ little in the vegetative stage. In the field at Rothamsted, they germinate at different times, *A. fatua* mainly in spring and *A. ludoviciana* mainly in autumn and winter. Within each species, considerable variation in seed characters has been observed and it is important

to know whether this is correlated with biological differences that may determine the behaviour of the different types as agricultural weeds, and affect the measures needed to control them.

Germination tests on the produce from the 22 selections of *A. fatua* and 7 of *A. ludoviciana* grown in pots in 1951 (1951 Report, p. 68), showed that the percentage of dormant seeds was higher in *A. fatua* (usually over 90 per cent) than in *A. ludoviciana* (40 to 80 per cent). This difference was mainly due to the low dormancy of the first seeds of the spikelets of *A. ludoviciana*. Of three selections of *A. fatua* with less than 80 per cent of dormant seeds, two resembled each other in some vegetative characters, and were like *A. ludoviciana* in colour of coleoptile and first leaf, number of shoots and early growth habit. Two selections of *A. ludoviciana* with dormancy higher than the rest were unlike in seed and plant characters and differed in dormancy from others which resembled them morphologically. There is, therefore, some evidence of a correlation between seed dormancy and vegetative characters in *A. fatua* but not in *A. ludoviciana*.

Another collection of wild oat seeds from more widely distributed localities in England and Wales and representing a larger number of seed types, was grown in pots in 1952. Representative types from the 1951 collection were included for comparison. Observations on the morphology and growth of the plants were made at intervals and seeds were collected for dormancy investigations.

Most selections of wild oats produced spikelets resembling those of the parents in colour, hairiness and articulation. Two selections of *A. ludoviciana* out of 28 and 2 of *A. fatua* out of 52 produced one or more plants with spikelets different markedly from the parent type. Both the divergent types of *A. ludoviciana* but only one of *A. fatua* were of the same species as the parent as judged by the articulation of the spikelet.

Eleven selections had spikelets differing from those of typical *A. fatua* and *A. ludoviciana* and intermediate in type between wild and cultivated oats; they had a small abscission scar at the base of the first seed only, a few hairs at the base, a slender rachis between the first and second seeds, and a well-developed awn on the first but not the second seed. Three of these produced only plants with spikelets of the same type as the parents, but the other 8 gave rise to varying seed-types, one of them producing 3 variations as well as the parent type. Of 10 aberrant plants, 7 were typical *A. fatua* judged by their spikelet articulation, while the other 3 were intermediate forms like the parents and differed from them only in husk colour and hairiness. None of the intermediate forms gave rise to seeds of the cultivated oat type, though some plants tended towards cultivated oats in width of leaf and sturdiness of culm. One of the aberrant seed-types produced by *A. fatua* was of this intermediate form. The intermediate types therefore appear to be related to *A. fatua*, but there is little evidence of relationship to cultivated oats and none at all to *A. ludoviciana*.

The relationship of spikelet characters to growth habit and morphology has not been fully worked out yet. On the whole vegetative differences within the species were not striking. An exception was the selection of *A. fatua* with grey, very hairy husks,

and a low percentage of dormant seeds in the 1951 test. The culms had hairy nodes and 3 other selections of similar seed-type also had hairy nodes. Most wild oats have entirely glabrous culms. Another difference associated with spikelet characters was the late-flowering of 3 selections of *A. ludoviciana* with grey, very hairy husks, though a fourth selection of this seed-type flowered at the same time as the other sorts of *A. ludoviciana*. Germination tests of seeds from these plants is not yet complete.

These results show that if spikelet characters are accepted as diagnostic of the two species *A. fatua* and *A. ludoviciana*, there is some overlapping between them in other characters, and that some types of wild oats cannot be included in either species. The status of these is uncertain; some of them may be hybrids. Present methods of study are unlikely to throw much light on the nature of the aberrant types; for this a cytogenetical investigation of the material is required. Meanwhile, plants and ripe seeds of all selections have been sent to Kew Herbarium for taxonomic study.

Physiological Relation of Virus Infection

The following investigations have been made in collaboration with the Plant Pathology Department.

Effect of a dark period before inoculation on susceptibility of leaves to infection. (E. C. Humphries and B. Kassanis)

Bawden and Roberts [1] have shown for several viruses and host plants that susceptibility to infection, measured by counts of necrotic local lesions, is increased if the plants are kept in darkness for a short time before the leaves are inoculated. Work has been started to determine what physiological changes induced in leaves on transfer from light to dark are responsible for this, and changes in the nitrogen fractions of the leaves have been investigated first. When tobacco or French bean plants are kept in darkness, the soluble fraction of the nitrogen in the leaf lamina increases, and nitrate accounts for most of the increase. On return to light after a dark period, the nitrate content falls. The numbers of local lesions produced by leaves of plants kept in light or darkness before inoculation, or in leaves inoculated at successive intervals after the plants were transferred from darkness to light, were usually closely correlated with the nitrate content of the leaves at the time of inoculation, although there were a few exceptions. The nitrate accumulated in the leaf lamina during a dark period was derived from protein, and the large increase in nitrate was accompanied by smaller changes in the contents of amino-N, amide-N and ammonia-N. Nitrate appears to be the end-point of proteolysis in attached leaves in darkness; the stage of nitrate production apparently proceeds rapidly compared with the earlier stages, so that intermediate products do not accumulate. The results suggest that susceptibility to infection may depend on the concentration of simple soluble nitrogen compounds present in the leaf at the time of inoculation, and that the increased susceptibility caused by darkening the leaves before inoculation may be due to an increased concentration of nitrogen compounds suitable for synthesis of virus.

(1) Bawden, F. C. and Roberts, F. M., 1948, Ann. app. Biol., **35**, 418.

The changes in phosphorus content of attached leaves of darkened plants were also investigated. Total phosphorus content tended to increase, but no consistent relation was found between phosphorus content and lesion counts.

Effect of infection with tobacco mosaic virus on the respiration of tobacco. (P. C. Owen)

Many workers have compared the respiration rate of healthy tobacco leaves with that of leaves infected with tobacco mosaic virus, but their results are inconsistent and sometimes contradictory. A systematic study has therefore been started of the effect of infection on respiration at successive intervals after inoculation. The results show wide variability in response to infection of comparable leaves between plants inoculated at the same time, and between batches of plants grown at different times and used at the same stage of development. The cause of this is not yet understood.

The leaves were inoculated by rubbing with infective sap, and in the earlier experiments the controls were rubbed with water. Some constituent of the sap acted as a spreader, so that less water was retained on the leaf surface after rubbing with sap than with water, and this caused an apparent increase in respiration rate of the leaves rubbed with sap if respiration rate was expressed on the basis of fresh weight after inoculation. In later experiments, therefore, the control leaves were rubbed with healthy sap, and respiration rate was expressed on the basis of final fresh weight or dry weight.

Effect of infection with beet yellows virus of beet mosaic virus on the respiration rate of sugar beet plants. (D. J. Watson)

Previous work (42) has shown that the loss of yield of field crops of sugar beet caused by infection with beet yellows virus (BYV) is partly due to a reduction in net assimilation rate. Though it is reasonable to attribute this mainly to a decrease in the rate of photosynthesis associated with yellowing of the leaves caused by infection, it may be due in part to increased respiratory loss of dry matter. Van Riemsdijk[1] found that the respiration rate of sugar beet leaves infected with BYV was 15 to 25 per cent higher than that of comparable healthy leaves, but there is no published information about the effect of infection on respiration in other parts of the plant. Infection with beet mosaic virus (BMV) also reduces net assimilation rate, but it is not known whether increased respiration is a contributory factor. An investigation has therefore been made of the effect of infection with BYV or BMV on the respiration rates of leaf lamina, petiole and storage root of sugar beet plants, grown in pot culture, at varying intervals after infection. The results are not yet complete, but the general conclusions are as follows:—The respiration rate of the leaf lamina was greatly increased by infection with BYV. The increase was greatest soon after the first appearance of yellowing; the respiration rate of the laminae of yellowed leaves at this time was more than twice that of comparable healthy leaves. The effect was progressively

[1] Van Riemsdijk, J. F. (1935) *Tijdschr. PlZiekt.*, **41**, 317.

smaller in younger leaves, and also diminished with age in the yellowed leaves. The respiration rate of the petioles was increased by infection, but less than that of the leaf lamina. The respiration rate of the roots was unchanged.

Infection with BMV had similar but smaller effects. The respiration rate of the laminae of infected leaves was never more than 25 per cent greater than that of comparable healthy leaves, and the increase was usually less than this. Increases of up to 50 per cent were found in the petioles. The respiration rate of the roots was unaffected.

In these respiration studies, the rate of CO_2 production was measured with an infra-red gas analyser. An automatic gas-sampling unit was designed for use with the analyser which enables the CO_2 concentration in four gas circuits to be measured and recorded in successive short intervals, so that the respiration rates of four experimental objects can be compared in one experiment and recorded automatically over long periods.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

Manganese Oxidation in Higher Plants *in Vivo*

(R. H. Kenten and P. J. G. Mann)

Last year the oxidation of manganese was the subject of a Special Review in the Report. Work has continued on pea plants (*Pisum sativum* L.) in water culture experiments at high Mn^{++} concentrations and by injection of solutions of manganese sulphate. In both types of experiment a brown colour develops in the stem, more particularly at the nodes. This colour is in part due to the deposition of high oxides of manganese. The affected tissues give an instantaneous blue colour with benzidine and the brown substance can be extracted from the tissues with neutral solutions of pyrophosphate. The extracts so obtained give an ultra violet light absorption curve closely resembling that given by solutions of manganipyrophosphate. Some indication has also been obtained of oxidation of Mn^{++} in the leaves of the plants. In this connection it has been shown that suspensions of washed chloroplast material oxidize Mn^{++} in light, but not, or to a much less extent, in darkness. To demonstrate Mn^{++} oxidation in plants *in vivo* by the technique described toxic concentrations of Mn^{++} are necessary. It has already been shown that the oxidation takes place *in vivo* with physiological concentrations of Mn^{++}. At these concentrations of Mn^{++} *in vivo* it is possible that the Mn^{++} oxidation product is reduced by plant metabolites as fast as it is formed. The results suggest that the symptoms of manganese toxicity may be due, at least in part, to deposition of higher oxides of manganese in the tissues.

The Oxidation of Phenylacetaldehyde and Indoleacetic Acid by Peroxidase and Mn^{++}

(R. H. Kenten)

The system in pea-seedling sap which catalyses the oxidation of phenylacetaldehyde has been studied. This consists of a thermolabile factor which appears to be a peroxidase and a thermostable factor which can be replaced by Mn^{++}. A system with similar properties to that in pea-seedling sap can be constructed using horseradish peroxidase and Mn^{++}. The oxidation when catalysed by either pea-seedling sap or horseradish peroxidase and Mn^{++} proceeds with the formation of benzaldehyde and formic acid as two of the products, while the formation of H_2O_2 as an obligatory intermediate is suggested by the inhibiting effect of catalase. The mechanism of the reaction is obscure but the results suggest that manganese oxidation is involved in this reaction. It was previously suggested by analogy with the known aldehyde oxidases that indolacetaldehyde might be oxidized by the system to indoleacetic acid (IAA). If indoleacetaldehyde is oxidized in a

similar way to phenylacetaldehyde the main oxidation would be indolealdehyde and not IAA.

The system in pea-seedling sap which catalyses the oxidation of phenylacetaldehyde bears a marked resemblance to the known IAA oxidase of pea epicotyl and bean roots. This enzyme has been variously reported as an Fe-protein, a Cu-protein, and a flavo-protein-peroxidase system. In this connection it has been shown that horseradish peroxidase preparations alone will catalyse the oxidation of IAA, while peroxidase plus Mn++ is a more efficient catalyst of the reaction. The oxidation of IAA by peroxidase and Mn++, like the known IAA oxidase, leads to the production of CO_2 and a carbonyl compound and is completely inhibited by 0·001 M-diethyldithiocarbamate.

Purification and Properties of the Amine Oxidase of Pea Seedlings *Pisum sativum* L.

(P. J. G. Mann)

The amine oxidase of pea seedling extracts has now been purified several hundredfold. The final preparations obtained are about fifty times as active in catalysing the oxidation of putrescine, as recently described preparations of the diamine oxidase of animal tissues. These enzyme preparations catalyse the oxidation not only of the amines specified in a previous report (1950) but also that of D- and L-lysine. Ornithine also is oxidized, though at a very slow rate. The greater part of the original activity of the extracts towards putrescine is recovered in the final enzyme preparations, but much of the activity towards histamine, the phenylalkylamines, tryptamine and L-lysine is lost. This lost activity can be restored by adding peroxidase, equivalent in amount to that present in the original extract, to the amine oxidase preparation. This effect of peroxidase is, with some of the substrates at least, due to its catalysis of the oxidation of the primary reaction products. The addition of trace amounts of Mn++ produces a similar effect. It is not yet clear whether this effect of Mn++ is dependent on the residual peroxidase activity of the amine oxidase preparations. In the course of the fractionation of the extracts the bulk of the peroxidase is separated from the amine oxidase and preliminary experiments suggest that the method used for this separation may form the basis of an improved method of preparation of peroxidase.

The results so far obtained suggest that L-lysine is oxidized by the amine oxidase at the E-amino group and that oxidation leads to intra-molecular condensation to a ring compound. Evidence for cyclization has also been obtained with cadaverine, putrescine and L-ornithine. From cadaverine a derivative of Δ^1piperidine has been isolated in good yield and colorimetric tests suggest the presence of Δ^1 pyrroline compounds in putrescine and ornithine reaction mixtures. In view of the results with cadaverine it appears probable that the ring compound formed from L-lysine is Δ^1 piperideine-2-carboxylic acid. In this connection it is of interest that the corresponding saturated compound, piperidine-2-carboxylic acid, has recently been isolated from higher plants.

Metabolism of Tryptophan in Plants

(G. H. Wiltshire)

The essential aminoacid tryptophan is known to be a source of the vitamin nicotinic acid in animal tissues. There is some evidence that a similar conversion occurs in some plants, but the intermediate steps have not been demonstrated.

A fairly rapid oxidation of tryptophan was found in pea seedling extracts. The tryptophan is oxidized not by oxygen but by hydrogen peroxide generated in a " coupled reaction," e.g. the oxidation of aliphatic amines by amine oxidase.

1. $R{\cdot}CH_2{\cdot}NH_2 + O_2 + H_2O \xrightarrow[\text{oxidase}]{\text{amine}} R{\cdot}CHO + NH_3 + H_2O_2$

2. $C_{11}H_{12}O_2N_2 + H_2O_2 \xrightarrow[\text{peroxidase}]{\text{(tryptophan)}} H_2O + \text{coloured products}$

The enzyme catalysing reaction 2 which uses hydrogen peroxide to oxidize tryptophan was identified as peroxidase. This enzyme is already known to oxidize many aromatic compounds. Experiments are in progress to establish the nature of the products of reaction 2.

Leaf Ribonuclease

(M. Holden and N. W. Pirie)

Ribonuclease is present in the leaves of all species that have been tested and older leaves have higher activity than young. Purified preparations have been made from tobacco leaves and pea seedlings by precipitation with ammonium sulphate and acetone. The most active preparations from pea seedlings have been purified about one-hundredfold on a protein-nitrogen basis. The enzyme differs from pancreatic ribonuclease in its properties and its action on ribonucleic acid. The pH optimum on yeast ribonucleic acid is at about 5·6 compared with 7·7 for pancreatic ribonuclease. Although more thermostable than many enzymes the leaf ribonuclease is not so stable as the pancreatic enzyme. The action of pancreatic and leaf ribonucleases on ribonucleic acid (RNA) preparations made from yeast, uninfected tobacco leaves and tobacco mosaic virus has been compared. All the preparations are hydrolyzed at about the same rate, and when the action of pancreatic ribonuclease has gone to completion a " core " is left and only about 30 per cent of the phosphorus becomes unprecipitable with uranyl nitrate in tricholaracetic acid whereas leaf nuclease destroys completely the precipitability by this reagent. Leaf nuclease is able to break down the core left by the action of pancreatic ribonuclease on yeast RNA.

Most of these experiments were made on solutions containing about 4 g. of nucleic acid per litre; this is a lower concentration than that generally employed in studies of ribonuclease but even so it is unphysiologically high. Some progress has been made in the study of more dilute solutions so that the results can be related to those in which the substrate is the microsomal nucleoprotein from uninfected leaves. The position is still by no means clear but some of the differences that had been noticed between the kinetics of hydrolysis of leaf nucleoprotein and yeast nucleic acid are clearly

due to the different concentrations at which the two processes had hitherto been studied.

The Infectivity of Tobacco Necrosis Virus

(N. W. Pirie)

Work on the nucleoprotein of the normal leaf and the changes that it undergoes sheds considerable light on the factors that affect the initial infectivity of preparations of the Rothamsted strain of Tobacco necrosis virus and the persistence of infectivity under different conditions of storage. This problem has been tantalizing us for three years with striking but generally unreproducible results. We have now defined experimental conditions that introduce uniformity. The treatments that promote destruction of the normal nucleoprotein, ageing in the sap, treatment with chloroform, dialysis, etc. result in a relatively stable preparation whereas those that stabilize the normal protein, dilution of the sap, very rapid cold working, additions of azide, etc. give a preparation that can be unstable. Whether or not it is unstable depends on the other components of the fluid in which it is stored. The one to which we have recently devoted most attention is ascorbic acid. When the normal concentration in sap is increased about fivefold by the addition of 1 g. per litre, the resulting virus preparation is both relatively uninfective and unstable, but when added to most types of preparation, ascorbic acid acts as a stabilizing agent. Preparations made in the presence of azide are exceptions for they lose infectivity more rapidly in the presence of ascorbic acid than in water. The hypothesis with which we relate these phenomena is that the products of an enzyme action, perhaps hydrogen peroxide, is the inactivating agent and the juxtaposition of enzyme and virus together with the presence in the system of a substrate for the enzyme or a substance that can protect the virus from the products of the action, control the final infectivity. An elucidation of this mechanism should go far to explain the origin of the non-infective anomalous nucleoprotein in infected leaves to which we constantly call attention. (In collaboration with F. C. Bawden.)

Technological Production of Leaf Protein

(N. W. Pirie)

Little progress has been made during the past year in this work, which is done in collaboration with the Grassland Research Station, and application has been made to transfer that part of the work in which we are particularly interested, to Rothamsted.

The Properties of the Resistant Parts of Fungal Mycelia which would accumulate in Soils

(W. R. Smithies and M. V. Tracey)

The action of enzymes on a sample of mycelium of *Penicillium griseofulvum* has been studied. Autolysis of an air-dried sample causes a loss of about 60 per cent of the protein, 20 per cent of the chitin and 30 per cent of the carbohydrate. Subsequent treatment with "Trypsin" (extract of pancrease) leaves only about 15 per cent of the original protein insoluble. Snail digestive juice brings over 90 per cent of the residual chitin into solution as

N-acetylglucosamine, and about 80 per cent of the carbohydrate. Pancreatic amylase, and the several fungal enzyme preparations tried, had in contrast, practically no action on the mould carbohydrate. It seems therefore that, for this particular mycelium, significant amounts of protein and carbohydrate are not available to enzymic attack or are resistant.

The composition of two wood rot fungi, *Polystictus versicolor* and *Polyporus sulphureus* has been determined. Neither, however, contains any lignin-like substances, in contrast to the specimen of *Ganoderma applanatum* mentioned in last year's report.

A method has been developed for the estimation of glucosamine in the presence of amino acids and sugars which interfere, in general causing high values, with the conventional procedure of Elson and Morgan. It has been found useful in the examination of mycelium and plant extracts.

Evidence has been secured that the amino sugar formed on the hydrolysis of water-insoluble portions of fungal mycelium is not all derived from chitin. Removal of the non-chitinous glucosamine containing polymer increases the ease with which the remaining chitin is attacked by chitinase. It appears that glucosamine derived from chitin may account for from 20-80 per cent of the glucosamine present. In *Lycoperdon pyriforme* the " chitin glucosamine " appears to be about 20 per cent of the total, in *Botrytis fabae* about 35 per cent, in *Daldinia concentrica* about 60 per cent, and in *Penicillium griseofulvum* 80 per cent or more. A search for enzymes capable of breaking down the material giving rise to " non-chitin glucosamine " is being begun. A large number of bacteria have been examined for the presence of chitinase and the production of this enzyme has been found to be widespread. This property appears to be of interest in the identification of bacteria by biochemical tests and the work is being pursued with the assistance of members of the staff of the National Collection of Type Cultures. Three species of amoebae found in soil have been examined so far, with the help of the Soil Microbiology Department, and all were shown to produce chitinase. The observation by Whitaker that cellulase activity is increased in the presence of protein has been shown to be true for chitinase and since the addition of small amounts of protein may quadruple the observed chitinase activity it is likely to prove of great value in studying chitinase production by soil organisms. Two water-soluble polysaccharides isolated from *Phallus impudicus* and *Mutinus caninus* have been shown to be polyuronides. They are not identical with pectic acid as there are marked differences in the ease with which they and pectic acid are attacked by a number of fungal and animal enzymes.

Decomposition of Naphthalene and Chloronaphthalene by Soil Bacteria

(G. H. Wiltshire)

Collaborative work on the breakdown by bacteria of naphthalene and chloronaphthalene has been carried out with N. Walker and three strains of bacteria have been isolated. This work is described in the report of the Soil Microbiology Department.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

During T. W. Tinsley's secondment to the West African Cacao Research Institute, G. D. Heathcote was appointed to work on virus diseases of cruciferous crops. F. M. Roberts, on secondment to the Clove Research Scheme, Zanzibar, identified *Cryptosporella eugeniae* sp. nov. as the cause of serious die-back in clove trees, and obtained much evidence suggesting that sudden death is caused by *Valsa eugeniae* sp. nov. B. M. Hamlyn worked in Holland for a month, exchanging posts with Miss G. Molinaar, from Wageningen. Professor H. J. Brodie, on leave from the University of Indiana, spent five months in the department.

As the guest of the New York Academy of Sciences, in January F. C. Bawden attended a conference at New York on the Nomenclature and Classification of Viruses and Rickettsia. R. Hull attended meetings of the International Institute of Sugar Beet Research at Brussels in February and at Bergen op Zoom in March and December; he and L. F. Gates attended a conference on sugar beet yellows arranged jointly by the German Ministry of Agriculture and the European Plant Protection Organization at Cologne in September.

B. M. Hamlyn was awarded the degree of M.Sc. of Reading University and J. W. Blencowe the degree of Ph.D. of London University.

Viruses and Virus Diseases

Experiments with ultraviolet light

Various effects of exposing viruses and leaves to ultraviolet light were described in last year's report. Some of these have been studied in greater detail and the action of ultraviolet has been used to study the movement and distribution of viruses in leaves. Much evidence was gained that only the epidermal cells are affected when leaves are irradiated; the effects of ultraviolet irradiation are temporary if the leaves are exposed to visible light within 1 to 3 hours after they have been irradiated, but, if not, the epidermis is permanently injured. Virus present in the epidermal cells can be inactivated and appears to remain inactive whether or not the leaves are immediately exposed to visible light.

The production of lesions in inoculated leaves can be prevented by irradiation with ultraviolet light; the maximum length of time after inoculation that irradiation prevents lesion formation varies with different viruses and host plants; irradiating French bean leaves 8 to 12 hours after they had been inoculated with a tobacco necrosis virus usually had no effect on numbers of lesions, whereas lesion formation in *Nicotiana glutinosa* inoculated with tobacco mosaic virus was usually prevented by irradiating 18 to 24 hours after inoculation. This difference is interpreted as showing that different viruses take different times to multiply in and move from the epidermal cells. Infection was equally prevented by irradiation whether or not the inoculum contained some substance such as "Celite," which greatly increases the number of lesions produced

by a virus preparation. The suggestion that these substances may facilitate infection because they introduce virus particles into cells other than the epidermis, therefore, seems unfounded (Bawden).

Many aphid-transmitted viruses are optimally transmitted when aphids, which have previously been prevented from feeding, are fed for only a minute or so on infected leaves before they are transferred to healthy plants. Evidence was obtained that these viruses, of which typical examples are henbane mosaic, cabbage black ringspot, potato Y, cucumber mosaic and sugar beet mosaic, may occur predominantly in the epidermal cells of systemically infected plants. When both the upper and lower surfaces of leaves infected with cabbage black ringspot or henbane mosaic viruses were irradiated with ultraviolet, the sap expressed from the leaves was only about one-fifth as infectious as sap from comparable unirradiated leaves, although the epidermal cells amount to only about one-fifth of the total volume of the leaves. Using the conditions of a short feeding time that normally give the largest number of transmissions, aphids rarely transmitted these viruses from leaves that had been irradiated. When left to feed on infected leaves for 24 hours before being transferred to healthy plants, only a few aphids gave transmissions whether they had been feeding on irradiated or unirradiated leaves, but they gave as many from the one as from the other. Thus it seems that aphids can acquire this type of virus from deep-seated cells, but do so with much greater difficulty than from the epidermis.

Very different results were obtained with sugar beet yellows virus; aphids that have fed on infected leaves for only a minute do not transmit this virus, the transmission of which becomes increasingly probable the longer the time that aphids feed on infected plants before being transferred to healthy ones. This virus was transmitted about as frequently from irradiated as from unirradiated leaves, a result agreeing with other evidence suggesting that aphids probably acquire this virus from the phloem (Bawden, Hamlyn and Watson).

When tobacco mosaic virus is irradiated with ultraviolet light, its resistance to denaturation by heat can be changed. This change in properties is not directly correlated with the changes that lead to loss of infectivity, for the two properties are not affected simultaneously, and much more intense radiation is needed to affect the rate of heat denaturation than to destroy infectivity. The rate of denaturation by heat can be increased three times by prolonged exposure to ultraviolet radiation. Experiments with a *Rhizobium* bacteriophage showed that virus particles which still retain infectivity after preparations have been exposed to ultraviolet, are less stable and lose their infectivity sooner than do comparable but unirradiated particles; a similar phenomenon was also detected with trypsin, but not with the three plant viruses (tobacco mosaic, tobacco necrosis and tomato bushy stunt) tested. (Kleczkowski).

Effects of environment on virus multiplication

Commoner and others, working in the United States, found that the multiplication of tobacco mosaic virus could be inhibited by thiouracil and that its inhibiting effect can be counteracted by

uracil. In their work, pieces of inoculated leaf were floated on nutrient solutions containing the substances and were continuously illuminated. Using comparable conditions, we have confirmed their results, but we have also found that the extent to which thiouracil inhibits virus production depends greatly on the physiological condition of the leaves. More virus is formed in cut leaves if they are floated on solutions of sugar and phosphate than if they are floated on water; more is also formed if the leaves are illuminated than if they are kept dark, particularly if they are floated on water. Oddly enough, thiouracil has the greatest effect in decreasing virus production in conditions where otherwise most virus would be produced. For instance, the sap expressed from leaves 6 days after inoculation with tobacco mosaic virus usually gives a precipitin titre with virus antisera of about 1/256, if the leaves have been illuminated and floated on a solution containing sugar and phosphate; in the presence of 0·01 per cent thiouracil, the titre falls to about 1/4. Comparable leaves floated on water in the dark, give a titre of about 1/64, and this falls only to 1/32 in the presence of thiouracil.

When using viruses and hosts that react with necrotic local lesions, thiouracil resembles trichothecin in that solutions sprayed over leaves within a day of inoculation prevent the production of lesions. Its action, however, is not restricted to the early processes of infection, for the multiplication of tobacco mosaic virus in tobacco leaves can be arrested even after it has been proceeding for 3 or 4 days. The virus already formed seems to be unaffected, but such leaves develop necrotic lesions, something which neither the virus nor thiouracil causes alone. (Bawden and Kassanis.)

Last year we reported that plants inoculated with tomato bushy stunt and cucumber mosaic viruses failed to show symptoms if kept at 37°C for a day or more immediately after inoculation. This suggested that diseased plants might perhaps be freed from these viruses if maintained for long periods at high temperatures. Experiments to test this were made with systemically infected *Datura stramonium* plants, which were showing severe symptoms when they were placed in a glass chamber maintained continuously at 37°C. The plants produced many new shoots, all of which looked healthy and from which no virus could be obtained by inoculation to healthy test plants. Cuttings struck from these shoots, taken after 4 to 5 weeks at 37°C, mostly grew into healthy plants in which no virus could be detected, although a few developed symptoms and from these virus was readily isolated. When removed from the glass chamber after 5 weeks, tests failed to reveal any virus in the parent plants, but after 3 to 4 weeks under ordinary glasshouse conditions, those originally infected with tomato bushy stunt virus again developed symptoms, and virus was then also readily recovered from them. Obviously the virus content of the plants was much decreased by the high temperature and the new shoots produced were mostly virus-free, but even 5 weeks was insufficient to free the whole of the original plants. In experiments with carnation plants systemically infected with carnation ringspot virus (a prevalent virus that in some ways resembles the tobacco necrosis viruses), healthy plants were also produced from cuttings taken from new shoots produced while the parent plants were maintained at 37°C. (Kassanis).

Electron microscopy

In the hope of ultimately obtaining direct evidence about the mechanism of virus multiplication and of the sites where it occurs, most of the year has been spent developing techniques for cutting and examining thin sections of leaves. An old Minôt-type microtome has been adapted to give serial sections by direct mechanical advance down to 0·1μ, cutting with a glass fracture-edge.

The electron microscope has been fitted with a special objective pole-piece which allows the aperture to be adjusted both along and across the optic axis. To get the full benefit from the new lens, the whole of the power supply chassis of the microscope has been moved away from the microscope column, because alternating fields from the power transformers disturbed the image.

After some preliminary attempts with wax embedding media we adopted the methacrylate techniques of Newman, Borysko and Swerdlow (Science, **110**, 66 (1949)), using the harder isobutyl methacrylate instead of n-butyl methacrylate. This hard material is "plasticized" with cresyl phosphate to give a block of the desired hardness. The properties can be varied from a soft rubber-like material to a hard brittle glassy substance by altering the amount of plasticizer. Instead of 2-4 dichlorbenzoyl peroxide, which is heat-activated, we catalyse the polymerization of the methacrylate with phenylbenzoyl carbinol, which is light-activated. This allows all stages from fresh material to finished block without raising the temperature above 25°C.

The technique is now well advanced, and clear pictures of tobacco mosiac virus particles in cells of systemically infected plants are being obtained.

Less work has been done with clays than in recent years, but a start was made on methods of mounting which avoid artefacts caused by drying. This is essential if any studies of particle aggregation are to be made, and a simple method would also be useful for biological particles. Freeze-drying clay suspensions on to electron microscope grids has given promising results. (Nixon and Fisher).

Aphid-feeding measured by radioactive indicator

Previously the amount of material imbibed by aphids from leaves was measured by feeding them on plants growing in water-culture solution containing P^{32}. The rates of imbition were about 10μg per hour for the first hour of feeding, 40μg per hour for the next four hours, and 20μg per hour for the next nineteen. This suggested that aphids obtain little from the epidermis and mesophyll, and feed extensively only from the phloem. However, the results were not conclusive because, in plants obtaining P^{32} through their roots, the indicator might occur predominantly in the vascular system. So as to ensure that there would be activity in superficial cells, the experiments were repeated using leaves that had been floated in culture solutions containing P^{32}, a technique previously found to give high activity. The aphids still acquired little activity during short feeding periods, and both sets of data suggest that aphids acquire food in quantity only when their stylets are in phloem cells (Nixon and Watson).

Sugar beet virus diseases

Six viruses or strains that cause yellowing of sugar beet were described in detail in the Report for 1951. Their serological behaviour, transmission by aphids and the diseases they cause have been further studied, but their relations one with another still remain largely undetermined. The only two with which positive serological reactions have been obtained are the stock culture of sugar beet yellows (SBY) and a more virulent strain of it (SBYN) that causes more obvious necrosis on infected leaves. No antigenic differences were found between these two, and antisera prepared against either were completely adsorbed by the other. Sap from plants infected with SBYN gave higher precipitin titres; that this strain occurs at a greater concentration was also suggested by electron micrographs of sap, in which filamentous particles were seen more frequently than in sap from plants infected with SBY. SBYN was also more readily transmitted by aphids (Blencowe and Watson).

With all six isolates, fewer transmissions were obtained when test plants were colonized with many aphids than would be expected from the number obtained with one aphid. SBY and SBYN caused more severe leaf symptoms and reduced weight of tops more in plants colonized with many infective aphids than in plants colonized with few. Plants with mild symptoms were frequently obtained when SBY was transmitted by colonizing test plants with few aphids; this happened less frequently with SBYN. Virus transmitted from such plants gives many plants with mild symptoms, but always gives some symptoms comparable with those typically produced by the parent type. Sap from these mildly affected plants, unlike that from those infected with viruses obtained from Eire and the United States that cause mild yellowing, always precipitated with antiserum prepared against SBY.

Other workers have claimed that sugar beet yellows virus persists in aphids for as long as 15 days after they cease feeding on infected plants. We have not confirmed this; the ability of aphids to infect with SBY and SBYN falls considerably within a day of leaving infected plants and no infections occur after 72 hours, although one of the viruses causing a mild yellowing persisted in the vector for 5 days (Watson).

Experiments to test the effects of varying dates of sowing and singling sugar beet were again made at Dunholme, Sprowston and Rothamsted; the treatments comprised all combinations of three dates of sowing (March, April and May), and three times of singling (early, normal and late).

Many aphids appeared on the plants during July; they were at first more numerous on the early sown beet, but the largest populations ultimately developed on the last sown. *Aphis fabae* was numerous at all centres; *Myzus persicae* was numerous at Dunholme and Sprowston, but rare on the beet at Rothamsted, although it was plentiful on other crops nearby.

Symptoms of yellows first showed on a few plants by early July after singling was finished, so varying singling date, as was to be expected, did not affect the incidence of yellows as it has in some other seasons. The first infected plants were seen among the early-

sown beet, but spread was more rapid in the later-sown beet, which had larger populations of aphids. At Dunholme and Sprowston, however, nearly all the plants of all ages were infected by autumn. At Rothamsted only a small proportion of the plants was infected. The largest yields were obtained this year from beet which had been sown and singled early (Blencowe).

Samples of all stecklings used for sugar-beet seed crops in Great Britain were planted at Dunholme. Counts in June 1952 showed that the 131 samples had a mean value of 0·7 per cent plants with yellows. Forty-five samples from isolated districts had a mean of 0·7 per cent plants with yellows, and a range of 0–5·8 per cent. Forty sprayed beds in Eastern England had a mean of 1·8 per cent, and a range of 0–27 per cent. Twelve beds grown under cover crops had a mean of 0·3 per cent and a range from 0–2·5 per cent, and thirty-four beds which were sprayed and under cover crops had a mean of 0·1 per cent infected plants, and a range from 0–1·5 per cent.

Steckling-bed inspections were again organized in the autumn of 1952. Out of 110 beds, 101 showed less than 1 per cent of the plants with yellows. Five of those with more than 1 per cent were beds that should have had cover crops, but these had failed, so virtually they were early-sown open beds. The other four were sown very early and spraying had not given adequate control.

Stecklings sown on three dates were thinned to three different spacings to give roots of varying size, and in the autumn they were kept in the root store (warm), in a shed (cool) or outwintered in the ground. When planted out in the spring, over 80 per cent of the roots grew, except those from the late sowing, of which only 18 per cent kept in the root cellar and 28 per cent kept in the shed grew. Juice from these roots had a refractometer reading of 3–6 per cent sucrose, the same as from the middle sowing, of which 80 per cent grew. All other samples had refractometer readings above 6 per cent sucrose. Thus the close relationship between refractometer reading and plant establishment found earlier did not recur this year. The very favourable soil conditions, during and after transplanting this year, probably explain the better establishment with plants having low sugar contents. Although the different treatments were reflected in the size of the plants at first, the small plants grew more rapidly and by the end of June there were no differences in the average weight of the roots or overground parts of individual plants from any of the treatments (Cattrall, Hull and Osborne).

Experiments with systemic insecticides have been continued. Early spraying (August 31st and September 10th) had the greatest effect in reducing the incidence of yellows in steckling beds. October and November sprayings had almost no effect, as the aphid infestation declined during September. Systox was as effective as a mixture of Pestox III and XIV.

Three treatments combined factorially were tested for their effect on the incidence of yellows in the root crop: spraying with systemic insecticides compared with no spray; high and low plant populations; and plots infested artificially at the centre with alate compared with apterous *M. persicae*. The development of plants

with yellows showed that many infective aphids entered the crop while the plants were still very small. Three sprayings in June and July reduced the incidence of yellows by 50 per cent at the end of August and 30 per cent in mid-October. Plant population had only a small effect this year, the number of infected plants per unit area was similar on plots of high and low population. No effect of introducing alate or apterous *M. persicae* was noticed, because of the influx of aphids from other sources.

The effects of early spraying (1st week July), late spraying (last week of July), and spraying on both occasions, were investigated on plots of about 1 acre in six fields in Lincolnshire and Norfolk. At Swineshead all plots were nearly 100 per cent infected by the end of August; on one field, however, the sprayed plots were noticeably less yellow and when lifted showed a good increase in yield. At Wisbech yellows was slight and, although sprayed plots had fewer infected plants, no effect on yield was detected. At Stradsett yellows was more prevalent and was partly controlled by spraying (Gates).

Glasshouse experiments showed that *Rhopalosiphoninus staphyleae* transmitted SBYN about half as frequently as did *M. persicae ; R. staphyleae* transmitted sugar beet mosiac virus to one plant in fifteen but did not transmit yellow net virus to any fifteen plants (Cornford).

The effects of a virulent and a mild strain of yellows were compared in a breeder's line (Rose 7582) and a commercial variety (Sharpe's E).

The virulent strain produced symptoms earlier on more plants of the line than on Sharpe's E, though eventually the percentage of plants infected was the same. Some plants of Sharpe's E were very slow to show symptoms, and then symptoms were mild for a while; others quickly showed very severe symptoms and were severely stunted. The symptoms on the line were more uniform and less severe than on the worst affected Sharpe's E plants.

The mild strain produced symptoms more slowly in the line than on Sharpe's E. It caused much more intense yellowing on Sharpe's E than on the line, and this was reflected in the effect on sugar yield. The mean sugar yield for the nominally healthy plots (which became infected later in the season) was 55·4 cwt. per acre of sugar, for the plots infected with mild yellows 49·8 cwt. per acre and with necrotic yellows 42·3 cwt. per acre. Most of the loss was from a decrease in size of roots, and the mean effect of infection on sugar content was only 0·4 per cent.

Thirty-two single-plant progenies, raised in isolation plots along with sister plants, were infected with a mild strain of yellows, the necrotic strain, yellow net, beet mosaic and cucumber mosaic virus. The reaction of individual plants in each progeny to the necrotic strain varied considerably, indicating a lack of genotypic uniformity with this degree of inbreeding. However, there were obvious average differences between the progenies. Lines that gave the mildest symptoms usually also gave most symptomless plants. More consistent behaviour within lines was obtained with seed from self-pollinated plants.

The single-plant progenies all reacted similarly to mild yellows, except that some showed symptoms more slowly, and to beet mosaic virus. By contrast, the progenies differed strikingly in their reaction to cucumber mosaic virus. All plants of some progenies were crippled whereas others produced only small, ephemeral local lesions. Large differences also occurred with yellow net virus. Some progenies gave brilliant systemic symptoms on most plants, whereas others gave only localized symptoms or none (Hull).

Virus diseases of cruciferous crops

Of two isolates of cauliflower mosaic virus (ClMV), the one that caused the more severe symptoms was also more readily transmitted. Both isolates were more readily transmitted to and from turnip plants than to and from cauliflower plants. Cabbage black ringspot virus (CBRV) was transmitted more readily by aphids from the lower leaves of infected turnip plants than from upper leaves: this was true whether plants had been systemically infected for 2 or 12 weeks (Hamlyn).

Of twelve species of aphids tested, *Brachycaudus helichrysi*, *Hyalopterus arundinis*, *Macrosiphoniella sanborni* and *Coloradoa rufomaculata* failed to transmit either ClMV or CBRV: *Brevicoryne brassicae*, *Myzus persicae*, *Myzus ascolonicus*, *Aulacorthum circumflexum*, *Macrosiphum euphorbiae*, *Megoura viciae* and *Sappaphis radicicola* transmitted both, and *Hyperomyzus lactucae* transmitted ClMV but not CBRV. Despite the many species that can transmit, the viruses seem to spread in the field only when either *Myzus persicae* or *Brevicoryne brassicae* are active.

In July and August there were unusually large migrations of *B. brassicae* across the middle of England, where both ClMV and CBRV spread extensively, whereas both were much less prevalent in the south and north. Plants were exposed during a migration on 26th July and, when flight had ceased, they carried populations of up to 1,200 aphids per plant. Unlike previous years, in 1952 CBRV was as prevalent as ClMV in some districts. The two viruses are differently distributed in infected plants. Both viruses invade the young leaves of freshly infected seedlings, but whereas ClMV remains equally distributed through all the plant, CBRV occurs predominantly in the older leaves, and the middle and upper leaves contain little or none. Migrating aphids mainly alight on middle and upper leaves; ClMV is much more readily transmitted than CBRV from these leaves, which may well explain the fact that ClMV is usually the more prevalent virus, despite the greater host range of CBRV, and the fact that from leaves showing pronounced symptoms aphids transmit it more frequently than they transmit ClMV. The greater ability of ClMV to invade and multiply in young tissues was further shown by its recovery from the curd and opened flowers of cauliflower and from the heart leaves of cabbage, whereas CBRV could not be transmitted from these parts of plants whose outer leaves had a high virus content and showed many ringspot lesions.

In two experiments seed-beds of cauliflower were sprayed at intervals of 7-10 days with Systox, Pestox 3, Parathion, Toxaphene, D.D.T., Pyrethrins and Pyrolan, but none significantly reduced

the incidence of either virus. Increasing the density of plant population by increasing the seeding rate did, as also did barriers of various types surrounding the beds. The barriers also reduced the number of infected plants per area of land and promise to be of practical value. Strips of barley and wheat were more effective than strips of mustard and kale or than simple physical barriers such as hop-lewing and sisal-kraft. These tests were with small seed-beds, and further experiments are needed to find what size bed can be protected from incoming aphids by such barriers (Broadbent and Heathcote).

Various yellow aphid traps were operated to test their relative efficiency. Moericke's 'Water-Bath' trap caught twice as many aphids as did a flat sticky trap of equal area, possibly because aphids crawl off the flat sticky flap. Cylindrical sticky traps of half and quarter the diameter of the standard size (5″) all caught approximately the same numbers.

The small sticky traps were more difficult to handle than the standard size, and the water trap required more frequent attention, but yielded undamaged specimens. The different traps seem to select different aphids; e.g. *Anoecia corni* formed only 1·3 per cent of total caught on flat traps, but 19·2 per cent on the vertical traps (Heathcote).

Potato virus diseases

Records made in 1952 on plants grown from tubers from the 1951 experiments showed that there was little spread of potato virus diseases in either the ware- or seed-growing areas of England and Wales. However, there was enough in experiments at Rothamsted to show that spraying with some insecticides was beneficial, particularly in preventing the spread of leaf roll. The experiment was made with Stock Seed Majestic potatoes and tubers infected separately with virus Y and leaf roll virus were introduced to give 0·65 per cent of the crop infected with each. The plants were sprayed altogether 7 times at intervals of 10-14 days. The table shows the percentage of infected plants in bulk samples of tubers taken at harvest and in selected samples taken from the five plants on each side of the introduced infectors. It would seem that most of the leaf roll in sprayed plots was brought in from outside and did not spread from the sources within the crop.

	% plants infected in bulk plot sample		% plants infected in 5 plants on each side of infectors	
	LR	Y	LR	Y
Unsprayed	5·4	8·2	23·9	50·8
D.D.T.	1·1*	3·6*	0*	14·6*
Parathion	1·2*	5·3	0*	15·6*
Isopestox	0·8*	7·7	0*	26·5*
Dieldrin	2·6*	6·1	10·0*	31·3
Toxaphene	2·8*	6·0	5·1*	30·5*

* significant decrease

(For details of formulation and application see report of Insecticides Dept.)

In 1952, in co-operation with the National Agricultural Advisory Service, and firms of insecticide manufacturers, commercial crops were sprayed with insecticides on two farms in Essex, to see for

how long a stock of potatoes can be maintained healthy in districts where virus diseases normally cause rapid degeneration (Broadbent).

Mycology

Spore dispersal and trapping

The wind tunnel was used to study the deposition of spores on sticky traps, including vertical and horizontal microscope slides, cylinders and Petri dishes such as are generally used in aerobiological surveys. Deposition occurs because of several effects acting singly or together. Gravity plays only a minor part. The catch is increased as the wind speed increases from 0·5 to 9·5 metres per second, but varies with both wind speed and the angle of the trap to the wind. The concentration of spores in the air is difficult to estimate from deposits on plane surface traps, because horizontal traps under-record at medium wind speeds and the catches on vertical traps vary greatly with changes in wind speed. Reliable data on spore concentration can be obtained only with power-operated suction traps (Gregory and Stedman).

Using suction traps, either the Cascade Impactor or Hirst's automatically recording trap, the whole range of spores in the air can be caught. These catches show that basidiospores, previously unrecognized as a major component of the "spora" (the spore population of the atmosphere) in both outdoor and indoor air can at times exceed all other components of the air spora. The concentration of coloured and colourless basidiospores, presumably from agarics and polypores, is maintained at over 1,000 per cubic metre for several weeks in late summer. Their diurnal fluctuation is peculiar, for most occur in the early hours of the morning. During some nights, very large numbers of minute basidiospores, thought to belong to the mirror yeasts, *Sporobolomyces*, have been recorded.

The improved trapping methods have also been used to estimate the concentration of spores of the dry-rot fungus, *Merulius lacrymans*, in affected buildings, and again high concentrations of basidiospores have been recorded (Gregory and Hirst).

Four non-suction traps (Vertical Cylinder, Horizontal Slide, Petri-dish and Funnel) were compared in the field with Hirst's suction trap. The results showed:

1. The absolute number of spores per cubic metre of air over a period of a day cannot be calculated from catches in a non-suction spore trap.
2. On days with the same mean wind speed, the efficiencies of both the horizontal slide and vertical cylinder varied by a factor of ten.
3. A smaller range of spore types was caught on the non-suction traps than on the suction trap.
4. The number of spores of any type caught per sq. cm. by the suction trap was more than 100 times as many as on the horizontal slide. The vertical cylinder caught relatively more pollens and relatively fewer spores of smut fungi, *Cladosporium* and *Alternaria*, than the suction trap.
5. The relative catches of spores in two funnels, one of which was shielded from rain, showed that many spores were carried down by rain (Gregory, Hirst and Last).

Potato blight

Potato blight developed late and slowly at Rothamsted in 1952; conditions were not well suited for experiments in which potato plants in pots were exposed in crops to find what conditions influence sporulation, dissemination, infection and incubation period of *Phytophthora infestans*.

To give information on the relation between conditions in potato crops and those under which normal meteorological records are made, continuously recording wet and dry bulb thermometers of various types have been operated at a range of heights both in and above the potato crop. In hot dry weather, particularly before the leaves are fully developed, mid-day temperatures are considerably higher, and relative humidity lower, at crop level than in a Stevenson screen at a height of 4 ft. At night, temperatures are similar but humidity is higher in the crop. When a full leaf canopy is established, and particularly when the soil is wet, temperatures are similar in crop and screen, but relative humidity is higher in the crop throughout the 24 hours. These, and other measurements from a balance which continuously records the weight of a potato shoot, have been used to study the conditions and times of formation and persistence of water droplets on potato leaf surfaces.

Meteorological data, including continuous records of temperature and humidity from several stations, were used to compare the applicability of various forecasting methods, and to test possible improvements. " Beaumont periods " measured at crop level were more frequently correlated with blight outbreaks than when measured in Stevenson screens. The feasibility of determining " Beaumont periods " at crop level, from daily recordings of wet and dry bulb maximum thermometers and a minimum thermometer, was tested at four stations. It seemed a possible method of reducing the cost and difficulty of maintaining a large network of forecasting stations, but too many inaccuracies were found to encourage further investigation or adoption of the method (Hirst).

Clubroot of cruciferous plants

The effect of various cropping treatments on the persistence of *Plasmodiophora brassicae* in soil was studied by box and pot experiments, using the production of clubs to measure treatment effects. Growing cabbage, ryegrass and poppies in infested soil reduced subsequent infection of susceptible plants. In one experiment the proportion of infected test plants was reduced from 57 per cent after fallow, to 28 per cent after cabbage and 19 per cent after ryegrass, but it has not been possible always to repeat this result.

While testing soil samples from Agdell Field, it was suspected that the *P. brassicae* there might differ in its host range from the organism which has been maintained for some years on cabbage in the greenhouse. A preliminary trial showed that turnip, swede and cabbage were heavily infected in Agdell soil, whereas only cabbage developed severe clubroot with inoculum from the stock cabbage plants. A more extensive experiment using fresh " isolates " of *P. brassicae* from both sources showed clear differences between them, as follows :—

Inoculum	% *diseased plants* — *Host*				
	Cabbage	Turnip	Swede	Radish	Cress (*Lepidium sativum*)
Cabbage— stock material	100	1	0	21	12
Swede— Agdell soil	100	68	100	0	88

Much attention was given to studying spore germination. Two methods of estimating germination have been used with spore suspensions: (1) removing small samples from the suspension, a procedure which is difficult because the spores clump; and (2) using small drops of suspension on slides, which can be examined directly. The second is better. Germination is influenced by the moist chamber in which the drops sit, the slide surface and the spore suspension. The last is the most important factor, and the proportion of spores that germinates varies from one suspension to another by five or more times. The stage of development of the gall from which the spores are extracted seems largely to determine the germinability of spores. Suspensions from old galls may contain up to 25 per cent empty spores, suggesting that spores can germinate as soon as the host cell dies. Spores have been suspended in water at 5°C for several months without apparent deterioration. Drying will kill about half the spores.

Methods for studying germination are now thought to be reliable enough to start an investigation of the way the rhizosphere affects germination (Macfarlane).

Cereal foot and root rots

An experiment which tested the effects of two years under different crops in freeing land from eyespot (*Cercosporella herpotrichoides*), take-all (*Ophiobolus graminis*) and weeds, showed that winter wheat following wheat or barley had 60 per cent of the plants infected by eyespot, and yielded 24·3 cwt. per acre; in April, 16 per cent of the plants had take-all, but sulphate of ammonia reduced it to 2 per cent at harvest. Where wheat followed oats or spring-sown ryegrass after a non-susceptible crop, only 14 per cent of the plants were affected by eyespot, there was no take-all and the yield was 35·7 cwt. grain per acre.

A similar experiment begun a year later gave similar results. Wheat following wheat had 77 per cent straws infected by eyespot and 17 per cent of the plants had take-all at harvest. One year free from wheat and barley reduced eyespot incidence to 38 per cent and take-all to 2 per cent. Two years free from wheat and barley but with autumn-sown ryegrass in one or both years, reduced eyespot to 24 per cent and take-all to 1 per cent. With potatoes instead of ryegrass, eyespot was reduced to 1 per cent and there was no take-all. Wild oats were abundant in continuous wheat, less abundant but still common after one year, and scarce after two years, under other crops. Striking differences in the appearance of the wheat after different rotations suggest that yields, which are not yet known, were again correlated with the incidence of disease (Glynne and Salt).

Two varieties of winter wheat (Bersée and Squarehead's Master) were grown on eyespot-infested land, to test the effects of varying seed rate, rate and time of application of sulphate of ammonia, and spraying with sulphuric acid in March. Decreasing the seed rate from 3 to 1½ bushels per acre decreased lodging and increased the yield of grain by 4 and 5 cwt. per acre in unsprayed and by 1 and 3 cwt. per acre in sprayed plots of Squarehead's Master and Bersée respectively. Spraying with sulphuric acid reduced the area of Squarehead's Master lodged at harvest from 95 to 36 per cent, eyespot from 88 to 39 per cent, and increased yield from 22 to 32 cwt. per acre. In Bersée, spraying reduced lodging from 54 to 1 per cent, eyespot from 84 to 34 per cent and increased yield from 33 to 44 cwt. per acre.

Responses to nitrogen were controlled by the earliness and the extent of lodging. This depended on the rate and date at which sulphate of ammonia was applied, for this determined the weight of straw but had little effect on the incidence of eyespot. Nitrogen applied in March caused most lodging in both varieties. In Squarehead's Master it failed to increase yield, whereas applied in October, April or May it caused less lodging and increased yield by 2 to 3 cwt. per acre. In Bersée all applications of nitrogen increased yield; March application, with 70 per cent of the area lodged, increased it from 29 to 33 cwt. per acre; October application, with only 47 per cent of the area lodged, yielded 38 cwt. per acre; April and May applications each yielded 32 cwt. per acre. When eyespot and lodgings were controlled by spraying yield was increased from 37 to 46 cwt. per acre by nitrogen applied in October, March and April, and to 43 cwt. per acre when applied in May. A yield of 49 cwt. per acre, one of the highest yields of wheat recorded at Rothamsted, was obtained by sowing Bersée at 1½ bushels per acre, spraying with acid and applying 4 cwt. per acre sulphate of ammonia in March (Salt).

Gibellina cerealis, a fungus which causes an interesting disease of wheat, hitherto recorded occasionally in Italy, once in France and once in Hungary, has been found in 17 of the last 18 years on the alternate wheat and fallow experiment on Hoos field, but nowhere else in Britain. It is as common after three as after one year's fallow; it severely affects individual plants, but attacks so few that it is unlikely to have affected crop yields, even in 1952 when it was commoner than in any other year. It infects barley, rye, Italian ryegrass and perennial ryegrass (Glynne).

Cereal Mildews

Observations on field crops showed that spring-sown cereals were much more heavily attacked by mildew than winter-sown cereals, and that the later the spring crops were sown, the more severely they suffered.

Experiments in glasshouses showed that the wheat variety Red Standard was more susceptible to infection by *Erysiphe graminis* at 14-20°C than at 7°C. After three days at 20°C before being inoculated, it was equally susceptible whether kept at 7°C or 20°C after inoculation. At 14°C pustules produced conidia more than ten times as rapidly as at 7°C.

The extent to which plants were affected was direcly correlated with their growth rate. Increasing the average growth rate was soon followed by an increase in the amount of infected leaf. When plants of different sizes were given equal amounts of nitrogen, the initially smaller plants became more heavily infected than the larger plants (Last).

Sugar beet diseases

Field experiments with seed treated with various fungicides showed that Panogen and ethyl mercury phosphate gave significantly better emergence than Agrosan. Granosan M and T.M.T.D. 1·33 per cent gave slightly better results than Agrosan, but differences were not statistically significant. Best emergence (56·0 seedlings per gram seed) was with seed dipped for 20 minutes in ethyl mercury phosphate solution at a strength of 30 parts per million; relative results were 49·9 for Agrosan and 37·4 for untreated seed (Gates).

Experiments were continued to study how wetting the cotyledons and leaves of sugar-beet seedlings before inoculation affects their susceptibility to infection by downy mildew (*Peronospora schachtii*) conidia. Some seedlings were wetted continuously for two days in the open, a treatment that retarded their growth rate and significantly increased the proportion that resisted attack by the fungus. This confirmed the result of an experiment made in August 1951. Similar experiments with potato blight fungus showed that wetting potato leaves also retarded their growth rate, but it increased their susceptibility to this fungus (Cornford).

NEMATOLOGY DEPARTMENT

B. G. Peters

At the end of September T. Goodey retired from the headship of the department but is continuing his work on a full-time basis. J. J. Hesling has been transferred from an A.R.C. Studentship to the scientific staff and A. R. Forster has been appointed an Experimental Officer. D. W. Fenwick was awarded the D.Sc. degree of the University of Wales. B. G. Peters gave a course of 12 lectures on the Platyhelminthes for the parasitology course at Imperial College, London, on a *locum tenens* basis.

Dr. J. Gallego returned to Spain after working for six months in the department. Mr. C. A. Loos of the Talawakelle Tea Research Institute, Ceylon, also worked in the department for six months making a critical study of eelworms attacking tea roots. In addition, three workers have attended for periods of 1 to 3 weeks to acquire techniques used in experimental work with species of *Heterodera* : Miss J. Bywater of Birmingham University, Mr. J. Keeping of Glaxo Laboratories, Ltd., and Mr. A. J. A. Pearson of Shell Chemicals, Ltd.

Material and Methods

Most members of the staff have shared the considerable work of identifying eelworm material sent in. An interesting case is the peculiar eelworm *Tylenchus fungorum*, unknown since first described by Bütschli in 1837, which occurred with a second species new to science in culture jars set up by Professor P. A. Buxton for the collection of insects which breed in toadstools. It appears certain that the females of both species must become parasitic in insects for the completion of their life cycles. A detailed and fully illustrated description of the eelworms has been accepted for publication (T. Goodey).

Two further cases concern root-knot eelworms. *Meloidogyne incognita* var. *acrita* has been identified as the cause of severe galling of tomatoes under glass, the identification being confirmed by testing the range of hosts susceptible to the eelworm, and *M. hapla* has been found to be damaging *Scabiosa caucasica* growing out-of-doors in a Suffolk nursery. Root-knot is thought of mainly as a glasshouse disease in this country, but several outdoor records are known from cultivated plants in England, and this year it has been reported from Italian ryegrass in Wales and from maram grass on the coast of Northumberland. It seems very likely that *M. hapla* is the species involved, and that it is indigenous (M. T. Franklin).

Several members of the staff have also sent out identified eelworm material, on request. This work of identification, exchanging material, and building up a departmental collection of mounted specimens is an important part of our activities. As the subject extends, morphological work makes increasing demands on powers of observation and necessitates new microscopical methods and equipment. Vertical illumination, through the microscopic objective, is now revealing fine surface structure previously obscure

(J. B. Goodey). Also, new techniques for staining and processing eelworms have been tested and adopted as routine where suitable (M. T. Franklin).

The department requires for its work a readily available source of living eelworms. This need, partially met by the small outdoor plots known as the Living Museum, inevitably grows. The root-knot eelworm, formerly regarded as a single species, *Heterodera marioni*, has suddenly come to be regarded as several different species of the genus *Meloidogyne*. This year has seen the establishing of four of these species, plus a distinct variety, in electrically heated beds of suitable soil in a greenhouse where (it is hoped) they will multiply on suitable host plants (M. T. Franklin).

Cysts of the potato root eelworm are used in very large numbers each year and something like mass-production methods are necessary in recovering them from soil by flotation, freeing them from other floating material by rolling, and handling them expeditiously. Work is proceeding on a mechanical rolling device which should save many hours of tedious work. Also, a simple apparatus has been adapted for picking up cysts by suction (J. J. Hesling).

Resistance and Susceptibility

Four degrees of susceptibility of a plant to an endoparasitic eelworm can be conveniently distinguished: (1) the eelworm may fail to enter the plant at all; (2) it may enter but fail to grow and reproduce; (3) it may grow and reproduce but fail to produce obvious disease symptoms; (4) it may produce disease symptoms. The situation can be complicated by differing behaviour of different biological races of any one eelworm species in different varieties of any one host species. Moreover, the degrees are not rigid categories: the result may partly depend on the level of infestation. All these points are illustrated by experimental results obtained this year.

Ditylenchus dipsaci

Old and new varieties of oats have been tested for susceptibility, for the National Institute of Agricultural Botany and the Welsh Plant Breeding Station, using three different rigorous techniques, which gave parallel results. Some oat varieties may possess a high degree of resistance which, however, is not always absolute (T. and J. B. Goodey). Various host range experiments on other races of *D. dipsaci* have been carried out including some on a race found attacking carrots in East Anglia (J. B. Goodey).

Ditylenchus destructor

Two populations, from potatoes and from mushroom mycelium, were tested in 8-inch pots on 10 varieties of potatoes, using the three inoculation rates: 9,000, 45,000 and 225,000 eelworms per pot, plus controls. No potatoes in the mushroom series were attacked, the haulms remaining normal and the new tubers quite clean, whereas all pots in the potato series produced infected tubers, with some indication that severity of attack was dependent on initial rate of inoculation. In spite of this universal attack no symptoms were shown by any variety at the lowest rate. At the middle rate

Arran Banner, Arran Pilot and Duke of York showed some stunting: the others were symptomless. At the top rate these two Arran varieties with Gladstone, Great Scot and Homeguard showed marked leaf symptoms, whereas the other five (Duke of York, Epicure, King Edward, Majestic and Ulster Chieftain) were symptomless (J. B. Goodey).

Heterodera rostochiensis

Cysts from 8 localities in the British Isles were used in an attempt to infect the variety of tobacco which was recently found, in Connecticut, attacked by a species of *Heterodera* very like *H. rostochiensis*. While eelworm larvae penetrated into the young seedlings (some local " races " more readily than others), none was found to have grown to maturity on older plants and no symptoms were seen (J. J. Hesling).

Interesting results came from a comparison of black nightshade, *Solanum nigrum* (into the roots of which larvae readily penetrate but fail to become adult) and tomato, a normal host. In heavily inoculated soil, although larvae penetrated tomato roots more quickly and initially in larger numbers, the tomato plants became severely stunted whereas *S. nigrum* did not, so that its larger root system finally took in a greater number of larvae. On the other hand, in lightly inoculated soil tomato took in the greater number. There appears to be a peak density of larvae per weight of root within 2 to 4 weeks, after which the density declines. This peak occurs earlier, and is more marked, in tomatoes than in *S. nigrum* (C. C. Doncaster).

Heterodera cruciferae

It is a matter of opinion whether this species causes symptoms in brassica crops. Transplantation of clean cabbage seedlings into soils containing up to 625 larvae per g. of soil showed that no obvious symptoms occurred at 125 l./g., while at 625 l./g. there was moderate stunting with intervenal chlorotic marbling after 9 weeks. So far as is known, such high population densities do not occur under field conditions, but a small field plot has been infected and is under observation (C. C. Doncaster).

Eelworm Population Changes

The rates at which populations of plant-parasitic eelworms build up and decline, and the various factors influencing such changes, are matters of importance especially among species of *Heterodera* which have few generations per season (often only one) but can survive many years in the soil in the absence of a host plant.

Heterodera rostochiensis

The rotation experiment, in which the effects of four different 3-course rotations are being measured in terms of eelworm population, has shown the expected rise in those plots carrying potatoes and a fall in the others but, so far, no differences are apparent between the various rotation crops other than potatoes (C. C. Doncaster).

Populations show interesting changes within one growing season. One way to reveal these is to grow potatoes in infested soil in

wooden boxes made up from 6 separate layers 2 inches deep. Eight such boxes were used, a pair being brought in and dismantled, layer by layer, after 5, 9, 13 and 19 weeks. The soil from each layer was washed to provide estimates of the cyst density (c/g.) and the density of eggs or larvae per cyst (l/c.), the product of these two criteria being the population index " larvae per g. of soil ", (l/g.). The soil originally contained 0·49 c/g., 71·9 l/c., and 35·0 l/g. Averaged over the whole box the cyst density showed a slight rise at 9 weeks, a significant rise to 0·96 c/g. at 13 weeks, and the greatest rise to 6·91 c/g. at 19 weeks. Owing to hatching, the density of larvae per cyst fell to a quarter of its original value at 9 weeks recovering to 42·4 l/c. and finally 229 l/c. The population index (l/g.) reflected this fall and rise and at 13 weeks was only slightly higher (40·6) than at the start; the phenomenal increase to 1,582 l/g. took place in the last 6 weeks, in July and August. Farmers rely on the last few weeks to give them an extra crop yield; in this way they also reap a harvest of eelworms. The separate layers showed that these same changes are delayed by up to 4 weeks in the bottom and top layers but, whereas the bottom layer had almost caught up at 19 weeks the top layer remained significantly reduced; the final l/g. data were: top: 714, 2nd layer: 2,254, bottom layer: 1,544 l/g. (B. G. Peters).

In 1951 a new edaphic experiment was set up in 32 pots each holding 20 lb. of soil. Bones Close soil was factorially modified by the addition of 35 per cent coarse sand (S), and 10 l. coarse peat (P) to half the pots. Mixed fertilizers were at two levels 5 g. and 25 g. (F), and 100 eelworm cysts were added to half the pots, giving 0·01 c/g. (H). Criteria were height of haulms, number and weight of tubers produced and (in the infested pots) eelworm population data. In this first year there were no significant effects of any kind, but the eelworm population increased to 0·24 c/g. In the second year fertilizers at the low rate were omitted. Height of haulms showed a strong fertilizer effect but haulms in infected pots were only slightly shorter. Number and weight of tubers produced, and weight per tuber, all showed a highly significant fertilizer effect and, while infection did not change the number of tubers, the total weight and weight per tuber were signifiantly reduced by eelworm. Cyst density increased on the average from 0·24 to 3·34 c/g. during the season but there was a highly significant fertilizer effect, the fertilized plots yielding 5·00 c/g. compared with 1·39 c/g in the unfertilized: a ratio of 3·6. Going back to the tuber weights and excluding the uninfected pots, 25 g. of fertilizers have increased the yield of tubers per pot from 30 g. to 474 g. but they have also increased the yield of cysts per pot from 12,500 to 45,000 (B. G. Peters).

Root Diffusates

In most species of *Heterodera* the larvae are stimulated to hatch from their egg shells and to leave the cyst in which they have been protected by a chemical substance diffusing in high dilution from the roots of certain plants. Usually, for any given species of eelworm, it is the host plants which produce the active diffusate but sometimes an " active " plant species is not a host for that

eelworm at all and sometimes a host is not active. For two species of *Heterodera*, the pea and cereal root eelworms, it is not yet clear that root diffusates are implicated. There are at least as many different diffusates as there are responsive species or races of *Heterodera*.

Diffusates are used as laboratory reagents to induce hatching, so that larvae can be counted. Moreover, since unhatched eggs within their cyst can survive in soil for many years while hatched larvae soon die without the host plant, there are theoretical possibilities of using active non-hosts, or artificially prepared diffusates, on a field scale to hatch out and starve out the larvae. The scope for research is very large.

Chemical nature

Research on the chemical nature of the active principle in potato (or tomato) root diffusate is being financed by the Agricultural Research Council and carried out at Reading, Cambridge and Rothamsted. At Reading Professor R. H. Stoughton is growing potatoes and tomatoes under glass by soil-less culture methods and extracting the active principle from the used culture medium with charcoal. At Cambridge Professor A. R. Todd is working on the chemical analysis of the active principle after removing it from the charcoal. At Rothamsted we are primarily concerned with the bio-assay of fractions produced by Cambridge, and the monitoring of the charcoal extraction carried out at Reading. In addition to this routine work four grades of charcoal have been tested for extracting natural samples of root diffusate, best results being obtained with a finely powdered grade. Used for 24 hours at 1 g/litre, 80 per cent of the original activity was removed. Experiments on the extraction of diffusates of different strengths suggest that saturation of the charcoal is one factor of importance (D. W. Fenwick).

Factors influencing production

Experiments were reported last year on the effects of age and variety of potato and of the presence of *H. rostochiensis* infestation, indicating that diffusate production is correlated with rate of growth of roots and (since infestation stimulates secondary root production) also with infestation. Further experiments this year along similar lines more or less confirm these findings, and especially the relationship between rate of growth and diffusate production. The results are being prepared for publication (D. W. Fenwick).

The same correlation has been found in uninfested tomatoes and *Solanum nigrum* (an " active " plant but not an efficient host), and in infested tomatoes. But in young infested *S. nigrum* plants, although root growth was not significantly affected, there was a marked inhibition of diffusate production. Conversely in older *S. nigrum* plants whose growth was retarded by larval invasion, diffusate production was comparable with that of uninfested controls. The reasons for this anomalous behaviour in *S. nigrum* are not yet apparent (C. C. Doncaster).

Breakdown of diffusate

Following the development of the bio-assay technique for potato root diffusate, reported last year, experiments have started on the breakdown of diffusate *in vitro* and in soil. Preliminary tests indicate that at room temperatures root diffusates lose considerable activity over a period of 3 to 4 weeks and this breakdown is not substantially decreased through sterilization by filtration. To obtain information on breakdown in soil a preliminary series of experiments using sand, peat and clay factorially has been started. Results are not yet available but there is some evidence to indicate that rate of breakdown in all three components is comparable with that in soil (D. W. Fenwick).

Other investigations

Among active non-hosts of *H. rostochiensis* several Gramineae have been claimed in the past. An experiment is in hand testing the hatching power of diffusates from 14 species of Gramineae; results are not yet available (J. J. Hesling).

There are many records of a winter dormancy period for *H. rostochiensis*, larvae failing to hatch in diffusate during winter months even though the diffusate was collected in summer. This dormancy is not found at Rothamsted and experiments show that it is due to the effects of winter conditions on cysts; cysts collected before winter and stored in the laboratory show normal hatching all the year round (D. W. Fenwick).

Chemical Control Methods

Pot tests

With the completion of the fourth annual test of nematicides against *Heterodera rostochiensis* in glazed pots of 20 lb. of infested soil, the method and the first year's results have been published (104). Analysis of the 1951 results showed that chlorobromopropylene used as a soil fumigant gave high kills closely similar to those given by equal doses of D-D mixture. The other nematicides were used as drenches in 1 l. of water. The only promising ones were a commercial chlorinated phenol and a chloroisothiocyanate. Poor kills were given by two chlorinated nitrobenzenes at up to 0·4g. per pot and no kill by elemental iodine (up to 0·45 g. per pot) or by parathion (up to 2 g. per pot, of a 27 per cent wettable powder). The only interesting effects on potato plants subsequently grown in the pots were increased yields of tubers from low doses of the two fumigants, greatly decreased yields from the high dose of iodine, and a large increase in the number (but not weight) of tubers from the parathion pots. This year a number of compounds based on 8-hydroxy-quinoline have been tested, data have been secured for probit analysis in respect of D-D and chlorobromopropylene, and D-D has been used to investigate kills at different depths of soil and at varying moisture levels. The final counts are not yet completed.

A separate experiment to find the effect on *H. rostochiensis* of dressings of ammoniacal gas liquor, was carried out by request in view of the possible use of this waste product as a source of

nitrogen, replacing ammonium sulphate which threatens to be in short supply. At the highest rate, corresponding to about 9,000 gallons per acre, there was a marked increase in yield of tubers and the eelworm kill was 35 per cent. However, so rapid was the recovery of the eelworm population on the extensive roots of plants in the treated soil, that the latter finally contained 3·5 times as many eggs as the untreated soil. This gas liquor can therefore not be recommended for use on eelworm land which is about to carry potatoes, in spite of its obvious fertilizer value (B. G. Peters).

Field tests

In conjunction with Mr. E. B. Brown of the National Agricultural Advisory Service (Cambridge), tests have been carried out on the control of *Aphelenchoides ritzema-bozi* (formerly known as *A. ribes*) on blackcurrants. Severe pruning and parathion spraying were tested, separately and combined, on a plantation of bushes. The results indicate that either method gives appreciable reduction of the infestation and that a combination of both is the most effective procedure (M. T. Franklin).

The co-operative experiment with Shell Chemicals, Ltd. and the West Norfolk Farmers' Manure Co., to test the effect on a potato root eelworm population of single and annually repeated D-D injections at various stages in a 5-course rotation, is now in its second year. Pre-treatment samples showed a satisfactorily high and uniform eelworm population over the 30 plots, but the 1951 D-D injections, at 400 lb. per acre, gave no significant kill, for reasons that are obscure. The experiment was sensitive to a kill of 15 per cent, but 6 per cent was measured. The soil is a fine silt and previous experience with this type of soil would have suggested a kill between 30 and 50 per cent (B. G. Peters and D. W. Fenwick).

Observations have continued on the relationship to Sitka spruce seedlings of *Hoplolaimus uniformis* and *Trichodorus* sp. These have been made at Ringwood forestry nursery on experiments carried out by the Chemistry Department. Formalin applied to the soil reduced the numbers of eelworms but did not eradicate them and they gradually came back to a normal level as time passed (J. B. Goodey).

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

M. J. Way returned to Rothamsted in July, 1952 after being seconded to the Clove Research Scheme, Zanzibar from 1950. Since his return he has been preparing his work there for publication until November 30th, 1952 when he resumed his work in the Department. His work in Zanzibar on the problem of *Theraptus* on coconuts has been widely commended, and is being followed up by the Colonial Office and the local Departments of Agriculture. Four papers have now been submitted for publication. These describe some effects of controlling the tree nesting ant *Oecophylla longinoda*. This was thought harmful because it attends and greatly benefits a Coccid which once was suspected as a possible vector of a disease of the Clove Tree. During this work it was found that *O. longinoda* is beneficial to coconut palms which it protects from attack by the Coreid bug *Theraptus* sp.; this bug was found to cause severe nutfall and Gummosis, hitherto attributed to poor soil. When attempts were made to encourage *O. longinoda* in coconut plantations, it was found that its relative scarcity was mainly due to three other ant species which although destructive to it do not prey upon *Theraptus* sp. Preliminary experiments were carried out on chemical control of one harmful ant *Anoplolepis custodiens*, and also on direct control of *Theraptus* sp. A Dieldrin emulsion was more effective than either D.D.T. or γ BHC emulsions as a spray treatment against the ant. The coconut yield in one area was increased by more than x10 when the crowns of cocnut palms were dusted fortnightly by hand with 0·4 per cent γ BHC to destroy *Theraptus* sp.

Miss H. Salkeld of Ontario Agricultural College completed her work for a Ph.D. of London University, and was awarded the degree. A paper on the effect of the age and stage of development of eggs on their resistance to insecticides which is based on her thesis has been accepted for publication.

M. Elliott has also been awarded the degree of Ph.D of London University for part of his work on the synthesis of the pyrethrins.

Miss C. Hutt married and left the department, she has been replaced by Miss D. Holbrook.

M. Elliott, K. A. Lord, A. H. McIntosh and C. Potter attended the IIIe Congrès International de Phytopharmacie in Paris. C. Potter presided over the Commission for the standardization of Biological Assay Techniques. At the invitation of the organizers, he also gave a Congress Lecture on the " Mechanism of action of insecticides ", and was awarded a Congressional Medal.

At the invitation of the Kenya and Tanganyika Pyrethrum Boards, C. Potter, in company with J. Furlong, Principal of the

Colonial Products Advisory Bureau, visited Kenya and Tanganyika on behalf of the Colonial Office, in order to advise the Pyrethrum Boards on the problems of the Pyrethrum industry. A visit was also made to the Belgian Congo at the invitation of the Pyrethrum Growers there. At the invitation of the Colonial Office C. Potter visited Zanzibar to discuss the problem of *Theraptus* on coconuts and to be informed on the work on Sudden Death and die-back of Cloves, he also visited the Colonial Insecticides Research Unit in Arusha, Tanganyika.

Chemical

Physical Chemistry

The effect of particle size of suspensions of contact insecticides on their toxicity. A. H. McIntosh has continued to work on this subject. Previous work, on injection of insecticidal suspensions into adult milkweed bugs (*Oncopeltus fasciatus*), had suggested that the difference in speeds of action between colloidal and crystalline forms of the one poison depended on the ratio of dose to solubility of poison in oil.

Tests, begun last year and now completed, show that this does not hold in contact action. Biological tests were made on adult saw-tooth grain beetles (*Oryzaephilus surinamensis*) with D.D.T. and eight of its analogues, none of which showed fumigant action. Further, there is no relationship at all between absolute toxicity of a D.D.T.-like compound and its solubility in oil.

The first step in penetration of insect cuticle by a poison is considered to be solution in the wax layer of the epicuticle. This wax layer is thin and will easily become saturated with poison from colloidal particles, no matter how high their lipoid solubility is. It is assumed that the rate at which saturation is reached is the same for all colloidal analogues. It has not been possible to measure the speeds at which crystals of analogues dissolve in wax from *O. surinamensis*. However, a method has been worked out for measuring the speeds at which deposits from suspensions of crystals dissolve in olive oil. There are big differences in the rates at which the crystalline forms of different analogues dissolve; crystals of different poisons but of the same size do not necessarily dissolve at the same speed. If the crystals dissolve slowly, there is a large difference in speed of insecticidal action between crystalline and colloidal poison. (This is measured by comparing the kills from crystalline and colloidal poison on insects kept cool after treatment and inspected after one day). There is, in fact, a correlation coefficient of 0·92 between difference in speed of insecticidal action and rate of solution of crystals.

Another factor which may influence difference in speed of insecticidal action is the stability of the film left on an insect's body by treatment with a colloidal suspension; these films show a greater or lesser tendency to crystallize as time passes. If the crystallization is very rapid, the advantages of applying poison as a colloid may be nullified. However, it was found that, although the colloidal analogues showed great differences in their ability to crystallize in films on glass, there was no relationship between speed of crystal-

lization and difference in speed of action of colloidal and crystalline analogues.

All the biological tests in this series have been carried out on adult *O. surinamensis* by dipping. The tests are now being repeated on adult mustard beetles (*Phaedon cochleariae*) by dipping, and on adult mealworms (*Tenebrio molitor*) by placing measured drops under the wings.

Effect of surface active agents on the toxicity of contact poisons. This work has remained in abeyance during the current year.

Biochemical

The work, started in previous years by K. A. Lord and C. Potter on the study of insect esterases and choline-esterases has been continued and extended during the past year. Non-specific esterases which hydrolyse phenylacetate have been shown to be present in all the insects tested to date. However, evidence based on the insect extracts tested to date indicates that choline esterase activity is less widely distributed.

During the current year much of the work has been designed to provide further information, first on the relationship between mammalian toxicity and insecticidal activity, in the hope that relatively non-toxic compounds of high insecticidal activity might be developed on rational lines; secondly on the correlation between anti-esterase activity and insecticidal activity; thirdly on the relative importance of any particular esterase or groups of esterases in the poisoning process.

A comparison of the relative toxicities of paraoxon, TEPP, parathion and two of its analogues with their capacities to inhibit insect esterases and choline-esterases has been made in four species of insects, viz. *Blattella germanica* adult, *Tenebrio molitor* larvae, *Dysdercus fasciatus* and *Tribolium castaneum* adults. The toxicities of the three isomers of parathion to those four insects species were, in order of increasing toxicity:—

O:O-diethyl O-(p-nitrophenyl) thiophosphate (Parathion) O:S-diethyl O (p-nitrophenyl) thiophosphate O:O diethyl S-(p-nitrophenyl) thiophosphate. This is in the reverse of the order of their toxicities to rats as reported by Aldridge, N. W. and Barnes, J. M. (1952), Nature **169,** 345.

Paraoxon was more toxic than parathion both to the four insect species and to rats. TEPP was of the same order of toxicity as the parathion isomers to all four insects species, but its exact position relative to the other compounds varied with the species.

Taking the substances as a whole, if they are arranged in order of increasing inhibitory power to either general esterase or choline-esterase, this order is not a guide to the order of the compounds in increasing toxicity to the insect from which the enzymes were derived. However, it is perhaps significant that the parathion isomer O:S-diethyl O-(p-nitrophenyl) thiophosphate is a better inhibitor of the general esterase for each of the four insects species tested and is also more toxic to them than O:O-diethyl S-(p-nitrophenyl) thiophosphate, but the reverse is true of inhibitory power

to choline-esterases, both insect and mammalian, and of toxicity to rats.

In the case of adults of both *B. germanica* and *Tenebrio molitor* the amount of each inhibitor required for inhibition of the general esterase is less than that required to inhibit the choline-esterase for the corresponding insect. This suggests that it is the inhibitor of the general esterase which usually causes death in the insect, a view which receives support from studies on the *in vivo* inhibition of the two enzymes in *T. molitor* which have been treated with paraoxon.

Pure Parathion, as reported previously, is not an effective esterase inhibitor, but when applied to insects *in vivo* it is rapidly converted into a powerful esterase inhibitor. The evidence for this is that extracts from insects poisoned by external application of pure parathion show marked anti-esterase activity.

Further work of a preliminary nature has been carried out on insect enzymes other than esterases.

Relationship between chemical constitution and insecticidal activity

Materials of plant origin which have insecticidal activity are frequently less toxic to mammals than many of the synthetic compounds which have been widely used for pest control in recent years. Chiefly for this reason compounds related to naturally occurring materials have continued to be those mainly studied in this department in the above connection.

N-iso*butylcarboxyamides*. A number of *N-iso*butyl amides of straight chain acids with varying degrees of unsaturation have been isolated from plant sources by various workers. They have in common a sialogogue activity and several have been claimed to show considerable toxicity to various insect species, especially the housefly, *Musca domestica* L. Leading references are cited by Crombie, J. Chem.Soc., 1952, 2997.

The objects of the work described below have been two-fold:—(1) to assist Dr. L. Crombie (Imperial College of Science and Technology, Organic Chemistry Department) in chemical investigations he is carrying out on the structure and synthesis of the insecticidal materials, pellitorine and herculin, and (2) to try to throw light on structure-toxicity relationships in compounds of this type. This study continues work outlined in the Annual Reports for 1949 and 1951. The results obtained so far give fair promise of revealing interesting structure-toxicity relationships in a field hitherto almost unexplored and an indication of a considerable degree of species selectivity in the potency of some such materials has been obtained.

The compounds tested and their insecticidal activity are shown in Table I. The bioassay was performed by P.H. Needham using a technique described elsewhere.

Jacobson (J. Amer. Chem. Soc., 1949, **71**, 366) proposed the gross structure *N-iso*butylnona-1:5-diene-1-carboxyamide for the insecticidal sialogogue, pellitorine, isolated from the roots of *Anacyclus pyrethrum* D.C. (for references, see Jacobson, *loc cit.*, and

Crombie, J. Chem. Soc., 1952, 4338). Compounds 1–4 in the table are the four possible geometrical isomers of this structure, specimens of which were supplied by Dr. L. Crombie. None showed appreciable toxicity as tested here and Crombie, *loc cit.*, on the basis of chemical evidence and these results has concluded that the above structure does not represent the insecticidal material from this source. Chemical and light absorption evidence (Crombie, Chemistry and Industry, 1952, 1034) indicated that the toxic compound in pellitory root extract might be *N-iso*butylnona-*trans*-l-*trans*-3-diene-l-carboxyamide (Compound 7). Whilst a synthetic specimen of this *iso*butylamide showed appreciable toxicity to *Musca domestica* L. (Crombie, Chemistry and Industry, *loc cit.*) it had negligible toxicity to *Tenebrio molitor* adults even at a concentration of above 10 per cent w/v. in acetone, whilst pellitorine, m.p. 72°, gave a 45 per cent kill at 3·13 per cent w/v. and a crude material, m.p. 49°, a 96 per cent kill at 3·15 per cent w/v. However, preliminary results indicate that the crude material, m.p. 49°, is only 4·4 times as toxic as the synthetic *N-iso*butylnona-*trans*-l-*trans*-3-diene-l-carboxyamide to *Blatella germanica*. Therefore it appears that the relative toxicity of the latter synthetic material and the crude natural extract varies with the species examined and this phenomenon is being investigated further.

Again Jacobson (J. Amer. Chem. Soc., 1948, **70,** 4234) proposed the gross structure *N-iso*butylundeca-1:7-diene-l-carboxyamide for herculin, the insecticidal sialogogue from the bark of *xanthoxylum clava-herculis* L. (for further references, see Crombie, J. Chem. Soc., 1952, 2997). Specimens of compounds 11–14 in the table have kindly been given by Dr. L. Crombie and are the four possible geometrical isomers of Jacobson's structure for herculin. None showed appreciable toxicity as tested here and this provides some support for Crombie's conclusion that herculin is not a stereoisomer of *N-iso*butylundeca-1:7-diene-l-carboxyamide.

A few other *N-iso*butylamides were also examined, but as shown in the table, none showed appreciable toxicity.

Pyrethrin-like compounds. The examination of the relationship between insecticidal activity and structure of synthetic compounds to the natural pyrethrins related has been continued.

The compounds in this series are esters of 2-alkyl and -alkenyl-3-methyl*cyclo*pent-2-en-4-ol-l-ones with various optical and geometrical isomers of 2:2-dimethyl-3-*iso*butenyl-*cyclo*propane-l-carboxylic acid (chrysanthemic acid). In the Report for 1951 some results on the toxicity of various forms of this acid and compounds related to it were presented. Work can now be reported which relates to variations in the alcoholic part of the molecule.

1. The effect of reducing the >C=O group to >CHOH in the keto-alcoholic part of the molecule has been examined. M. Elliott has found that allethrin (the ester of (±)-2-allyl-3-methyl-*cyclo*pent-2-en-4-ol-l-one with (±)-*cis-trans*-chrysanthemic acid) can be reduced by means of sodium borohydride to (±)-2-allyl-3-methyl*cyclo*pent-2-en-1:4-diol-4-(±)-*cis-trans* chrysanthemate. Only the ketone group in the *cyclo*pentenone ring is affected in this reaction. The reduced compound is only 1/10th as toxic to *Phaedon cochleariae* adults as the parent keto-ester.

Toxicity of various N-iso*butylcarboxyamides to* Tenebrio molitor *adults*

No.		*Concentration* (% w/v. in acetone)	% *Kill*
1.	*N-iso*butylnona-*trans*-l-*trans*-5-diene-l-carboxyamide $Pr^n.CH^t{=}CH.(CH_2)_2.CH^t{=}CH.CO.NH.Bu^i$	1·92	4
2.	,, ,, ,, *cis*-l-*trans*-5- ,, ,, ,, $Pr^n.CH^t{=}CH.(CH_2)_2.CH^c{=}CH.CO.NH.Bu^i$	2·02	0
3.	,, ,, ,, *trans*-l-*cis*-5- ,, ,, ,, $Pr^n.CH^c{=}CH.(CH_2)_2.CH^t{=}CH.CO.NH.Bu^i$	1·92	4
4.	,, ,, ,, *cis*-l-*cis*-5- ,, ,, ,, $Pr^n.CH^c{=}CH.(CH_2)_2.CH^c{=}CH.CO.NH.Bu^i$	2·64	0
5.	Pellitorine, m.p. 72-4°, isolated by Jacobson's method	3·13	45
6.	Pellitory root extract, m.p. 49°, isolated by chromatography	3·15	96
7.	*N-iso*butylnona-*trans*-l-*trans*-3-diene-l-carboxyamide $Am^n.CH^t{=}CH.CH^t{=}CH.CO.NH.Bu^i$	3·37 10·81	0 4
8.	Stillingic acid *N-iso*butylamide $Am^n.CH{=}CH{\cdot}CH{=}CH{\cdot}CO{\cdot}NH{\cdot}Bu^i$ (stereoisomer of 7)	4·09 10·50	4 4
9.	*N-iso*butylnona-*trans*-l-ene-l-carboxyamide $Pr^n.(CH_2)_3.CH^t{=}CH.CO.NH.Bu^i$	2·19	0
10.	,, ,, ,, *cis*-l- ,, ,, ,, $Pr^n.(CH_2)_3{\cdot}CH^c{=}CH{\cdot}CO{\cdot}NH{\cdot}Bu^i$	1·97	0
	Nos. 1–10 are compounds related to pellitorine		
11.	*N-iso*butylundeca-*trans*-l-*trans*-7-diene-l-carboxyamide $Pr^n.CH^t{=}CH.(CH_2)_4.CH^t{=}CH.CO.NH.Bu^i$	2·13	0
12.	,, ,, ,, *trans*-l-*cis*-7- ,, ,, ,, $Pr^n.CH^c{=}CH.(CH_2)_4.CH^t{=}CH.CO.NH.Bu^i$	1·09	3
13.	,, ,, ,, *cis*-l-*trans*-7- ,, ,, ,, $Pr^n.CH^t{=}CH.(CH_2)_4.CH^c{=}CH.CO.NH.Bu^i$	1·96	0
14.	,, ,, ,, *cis*-l-*cis*-7- ,, ,, ,, $Pr^n.CH^c{=}CH.(CH_2)_4.CH^c{=}CH.CO.NH.Bu^i$	2·01	0
15.	"neo-Herculin" m.p. 64·5-66° (cf. Crombie, *loc. cit.*)	2·00	70
16.	*N-iso*butylauramide $Me.(CH_2)_{10}.CO.NH.Bu^i$	2·33	3
	Compounds 11–16 are related to herculin as formulated by Jacobson		

No.		*Concentration* (% w/v. in acetone)	% *Kill*
17.	*N-iso*butylpenta-*trans*-l-*trans*-3-diene-l-carboxyamide $Me.CH^{L}CH.CH^{L}CH.CO.NH.Bu^{i}$	2·31	0
18.	*N-iso*butylpenta-*cis*-l-*trans*-3-diene-l-carboxyamide $Me.CH^{L}CH.CH^{G}CH.CO.NH.Bu^{i}$	2·38	0
19.	*N-iso*butylheptadeca-16-ene-8:10-diyne-l-carboxyamide $CH_2{=}CH.(CH_2)_4.C{\equiv}C.C{\equiv}C.(CH_2)_7.CO.NH.Bu^{i}$	1·61	0
20.	Capsisicin Extract (B.P.)	4·61	0

2. Allethrin is a mixture of the eight possible isomeric forms derived from (±)-*cis-trans*-chrysanthemic acid (4 isomers) and (±)-allethrolone (2 isomers). Crystals of the " α-dl-trans " isomer of allethrin separate from this mixture on standing (Schechter, LaForge, Zimmerli and Thomas, J. Amer. Chem. Soc., 1951, **73,** 3541). This crystalline isomer must consist of " one of the racemic ester pairs, *d-trans* acid with *d*-allethrolone plus l-*trans* acid with *l*-allethrolone or *d-trans* acid with *l*-allethrolone plus *l-trans* with *d*-allethrolone ".

The ratio: $\frac{\text{toxicity of " } \alpha\text{-}dl\text{-}trans \text{ " isomer}}{\text{toxicity of (±)-allylrethronyl(±)-}trans\text{-chrysanthemate}}$ is $\frac{11}{95}$ to *Tenebrio molitor* adults, so that the remaining part, the non-crystalline " β-*dl-trans* isomer ", must be correspondingly more toxic than (±)-allylrethronyl(±)-*trans* chrysanthemate, which is a mixture of the " α-*dl-trans* " and " β-*dl-trans* " isomers.

It can be argued from this evidence that one optical isomer of allethrolone gives more toxic esters than its enantiomer. Furthermore this comparison is of interest because the " α-*dl-trans* " isomer has been suggested as an absolute standard of comparison for pyrethrin-like compounds.

3. Previous results (for summary, see Elliott, Pyrethrum Post, 1951, **2,** (3), 24) have indicated that the toxicity of esters of the type under consideration are independent of the optical form of the alcohol (which has an asymmetric carbon atom at position 4 in the ring). Dr. F. B. LaForge and co-workers have recently resolved cinerolone ((±)-2-*cis*-*n*-but-2′-enyl-3-methyl*cyclo*pent-2-en-4-ol-l-one) and through his kindness the esters of (+)-*trans*-chrysanthemic acid with the (+)-and (—)-forms of the above alcohol have been available to us. Against *Phaedon cochleariae* and *Tenebrio molitor* adults, the ester from the dextro rotatory form of the alcohol has proved to be 4 to 5 times as toxic as that from the corresponding laevo form of the alcohol. Mixtures of equal proportions of the esters from these two optical isomers of the keto-alcohols show the toxicity to be expected if these two forms act independently without synergism or mutual depression of activity.

4. The effect of altering the side chain of the alcohol in esters of chrysanthemic acid with various 2-alkyl and alkenyl-3-methyl-

*cyclo*pent-2-en-4-ol-l-ones has been examined. Most of the compounds used here were prepared by Dr. S. H. Harper and co-workers, to whom gratitude is expressed for the donation of samples. (c.f. *J. Chem. Soc.*, 1950, 971, 1152, 3552; 1951, 2445; 1952, 869). The results are summarised below.

The evidence indicates that the toxicity of the esters is greatest when there is a double bond in the 2′-position of the side chain of the alcohol and progressively decreases as this ethylenic linkage is separated by more methylene groups from the *cyclo*pentenone ring. The toxicity of esters from two independently prepared samples of cinerolone, which has the *cis*-but-2-enyl side chain, was appreciably greater than those from allethrolone. Saturation of the alcoholic, *cis*-but-2-enyl, side chain produced nearly the same decrease in toxicity as reduction of the ketone grouping in the *cyclo*pentenone ring. It may be significant that both these changes decrease the extent to which the α-methylene group in the side chain is activated. Again, when the double bond is in the 2′ position a methylene group is most highly activated and progressively less so when double bonds are in the 3′ and 4′ positions.

The overall conclusion is that the characteristic biological activity shown by pyrethrin-like esters is associated with the precise stereochemical configuration in which the acidic part of the molecule is held in relationship to the keto-alcoholic part of the molecule, and, in particular, the unsaturated side chain.

Organic chemistry

M. Elliott has continued his work on the synthesis of compounds related to the alcoholic and acid components of the pyrethrins.

Insecticides derived from plants

Pyrethrum. 1. The constituents of pyrethrum flowers.

The work on the chromatographic separation of the constituents of extract of pyrethrum flowers by K. A. Lord and J. Ward has been continued with a view to obtaining a complete separation of all the insecticidally active materials from one another and from the inactive constituents.

2. The insecticidal activity of strains of Pyrethrum.

At the request of the Kenya Pyrethrum Board a study has been made by E. M. Gillham and P. H. Needham of the insecticidal activity of some different strains of pyrethrum in relation to their pyrethrin content, as determined by chemical analysis. The work is part of a co-operative effort which is being organized by the Colonial Products Advisory Bureau.

The toxicity tests carried out in this department indicate that equal weights of total pyrethrins from different strains have not necessarily equal insecticidal activity. The results obtained depend on the test insect and technique of testing. The reason for the difference may lie in the differences in the ratio of " pyrethrin I " to " pyrethrin II ".

Heliopsis. Miss P. Smith has continued the cultivation of *Heliopsis scabra* and *Heliopsis parvifolia* for a second season. A proportion of both species did not survive the 1951–52 winter and the remaining plants made insufficient root growth for extraction

of the toxic principle. The two species are therefore being cultivated for a third season.

The work on insecticidal amides from other plant species are outlined in the section the relationship between chemical constitution and insecticidal activity.

Biological

Bioassay techniques

Measured drop technique. The measured drop technique has been in use throughout the year for the assessment of insecticidal action and has again proved to be very satisfactory.

P. H. Needham and A. J. Arnold have incorporated some modifications of the micrometer syringe designed to improve accuracy and speed of operation. A " clicking " device has been fitted to the micrometer syringe which gives one click for each microlitre delivered. In this way the operator can devote his whole attention to the positioning of the drop on the insect, and not have to watch the micrometer graduations.

Injection technique. The micrometer syringe used in connection with the measured drop technique may also be used for the injection of insects.

Extracts of three strains of pyrethrum have been tested in this way for both relative toxicity and depreciation due to the storage of the flowers. The results obtained showed the technique to be satisfactory and compared favourably with tests carried out on the same materials by our own measured drop technique and by other workers using different methods.

The test insects for these injections were male and female adult *Tenebrio molitor*, and both odourless distillate, and n-hexane were used successfully as media. The volume injected was 0·001 ml.

Technique of estimation of contact poisons. C. Potter and E. M. Gillham have continued the work on the examination of the relative importance of direct contact effects and residual film effects in laboratory insecticidal assay.

The effect of stage of development on insect resistance

Miss H. Salkeld has completed her work on the changes in resistance of insect eggs to insectidies that occur during development. This work has now been accepted for publication.

Toxicity and permanence of insecticidal deposits on plants

P. Burt and J. Ward have continued their work on the behaviour of insecticides on plant surfaces. A detailed report of the work to date has been submitted to the Colonial Insecticides Committee and is being prepared for publication.

Experiments using deposits of crystalline D.D.T. on films of plant wax spread on glass plates have been continued. It was found that when the D.D.T. was dissolved in the wax, it was more readily destroyed by irradiation with short-wave ultra-violet light than D.D.T. crystals. By working with duplicate plates, irradiating one of them with U.V. and then analysing both for D.D.T., an estimate can be made of the proportion of D.D.T. dissolved in the wax. In this way, it was shown that D.D.T. crystals 50μ long and

about 1μ in diameter did not dissolve to any appreciable extent in the wax layer on which they are lying, under conditions of free ventilation. This is true for plates stored for up to 14 days at either 18°C or 43°C.

The rate of loss of D.D.T. and of contact activity from crystalline deposits on leaves of plants kept in a greenhouse has been studied under summer and winter conditions, and compared with the rate of loss from glass plates kept alongside the plants. The difference in toxicity between fresh deposits on leaves and on plates, mentioned in the Report last year, seems to be due largely to the greater humidity of the environment of the test insects confined on leaves. For when insects were confined on deposits on glass plates at a higher humidity than usually, the kill was greater than that obtained under standard conditions. To obtain further confirmation, Cellophane was sprayed with a range of deposits of D.D.T. It was found, in a duplicated experiment, that the ratio of LD50's obtained from insects confined on moist and dry cellophane respectively was similar to the ratio on leaf and glass surfaces.

Leaves exposed in winter in the greenhouse (air temperature 10–20°C) lost about a third of their D.D.T. and of their contact activity after thirty-seven days, only a small part of this loss being due to leaf growth. In the Summer experiment, the plants were exposed to as much sunlight as they would stand, and air temperatures of 35°C were sometimes reached. Under these conditions, losses of D.D.T. amounted to about half in a fortnight. The losses during a given period appeared to be correlated with the daily maximum air temperature. In both the winter and the summer experiments, but particularly the latter, losses from the glass plates were greater than from the similarly treated leaves. The plates were found to reach a higher temperature than the leaves in sunlight, and this presumably caused the more rapid losses. It is concluded that the most important causes of loss of toxicity of deposits of crystalline D.D.T. on plants in a greenhouse are growth of the plant and volatilization of the D.D.T., and further that when a comparable formulation (e.g. a wettable powder) is used, volatilization is unlikely to be of practical importance as a source of loss of toxicity in a temperate climate, but may well be important in the tropics. Adult *Tribolium castaneum* has been used as the biological indicator of insecticidal activity throughout these investigations. A modified Schecter-Haller method was used for the chemical analysis.

The mechanism of selection of strains of insect resistant to insecticides

Dr. Tattersfield has completed the first stage of his work and two papers have been accepted for publication.

It was shown that the effect of repeated sprayings with D.D.T. upon the adults of a wild colony of *Drosophila melanogaster* found at Rothamsted gave rise to an increase in resistance. This was characterized by marked fluctuations, and the rate of increase depended upon the concentration of the insecticide used, the higher the concentration and percentage initial kill, up to a limit, the quicker resistance developed, but it was apparent that if continued for a sufficient length of time the same end-point was reached

finally if the concentrations used gave rise to any marked degree of selection. In the experiments there was no sign of any degree of adaptation, but the proportion of resistant insects in the initial population seemed of some importance. The process was a slow one.

During the course of this work the test insect developed a susceptibility to carbon dioxide and much time was spent examining the effect of this characteristic upon susceptibility to D.D.T. It was found that the insects whether susceptible or selected for their resistance to CO_2, gave the same probit-log. concentration regression line for D.D.T. if nitrogen was sued for anaesthesis prior to spraying. If tested at the temperature 25°C at which the CO_2-susceptibility disappeared, the same regression line resulted whether carbon dioxide or nitrogen were used for anaesthesis. Nitrogen has no toxic effect. Also if tested at a temperature of 13–15°C, at which the CO_2 killed 50 per cent of the test subjects against 2 per cent for nitrogen, and if allowance was made for deaths in the controls, the regression lines whether CO_2 or N is used for anaesthesis were identical. The conclusion was drawn that the effect of CO_2 is merely to limit the population from which selection for resistance to D.D.T. is made.

Work has continued and some data on the effect of D.D.T. on rate of reproduction have been accumulated; the evidence procured suggests a decline in the reproductive rate. An examination of the effect of the age of parents on susceptibility of the offspring was not conclusive.

A good deal of work has been carried out on the susceptibility to CO_2 shown by our strain of *D. melanogaster* and how it has arisen. The subject is most elusive as no physiological reason for its occurrence has yet been discovered. Such gases as nitrogen, ethylene acetylene, nitrous oxide are without effect, beyond a temporary anaesthesis. In contrast to the selection for D.D.T.-resistance, the resistance to CO_2 can be rapidly achieved. More detailed work is being carried out in collaboration with Dr. Kalmus of University College, London. Professor L'Heritier of France has kindly let us have samples of his CO_2-sensitive strain.

The work carried out by Mr. Kerr when at Rothamsted and described in the previous report has been written up and three short papers submitted for publication.

Insect rearing

The stock of plant feeding and stored product species have been maintained during 1952 and *Blatta orientalis* (Oriental cockroach), *Blatella germanica* (German cockroach) and *Oncopeltus fasciatus* (Milkweed bug) added to the list of insect cultures available for experimental work.

O. fasciatus are being reared on crushed Black Nigerian sunflower seed; blanched Nigerian peanuts were found not to be satisfactory for this purpose.

Mrs. J. Kenton has continued to work on aphid rearing and as a consequence the aphid stocks have improved during the course of the year. Mrs. Kenten has carried out detailed experiments to

test the effect of different photoperiods and temperatures on the production of the various forms of the aphid *Acrythosiphon pisum* (Harris).

Toxicity of plant-protective chemicals to bees

Mr. G. D. Glynne-Jones and Miss Connell have continued the work on the toxicity of plant-protective chemicals to honey bees at Seale-Hayne in collaboration with the department. In addition to the derived toxicity studies, a special investigation has been made into the possibility of systemic insecticides contaminating nectar and hence appearing in honey. Using Schradan labelled with 32p, this was shown to occur following the application of the insecticide as a foliage spray. Considerable evidence was obtained to support the view that contaminated nectar may result in Schradan appearing in honey in an unchanged form.

Field Experiments

Control of wireworms

In the experiment started in the autumn of 1951 in collaboration with Dr. Raw of the Entomology Department, only minor damage occurred on any of the plots so treatment differences were small. Since 1952 was the first year after ploughing in grass damage may occur in 1953. The results so far confirm the results of the previous experiment. Aldrin 200 lbs. per acre 1·78 per cent dust gave the best crop followed by Chlordane 100 lbs. per acre 5 per cent dust and BHC 56 lbs. per acre 3·5 per cent dust combine-drilled all of which were significantly better than the control. BHC seed dressing and D.D.T. 150 lbs. per acre 5 per cent dust did not improve the crop significantly above the controls.

Control of bean aphis (A. fabae *Scop.*) *on field beans*

M. J. Way, P. Smith and C. Potter continued to work on this subject.

A field experiment was carried out as described in the 1951 report but using Parathion, Systox, Nicotine, Pyrethrum with piperonyl butoxide, and D.D.T. in two formulations. These were applied once—on the 12th June soon after the beans became infested with aphid migrants from the winter host; the mean aphid population at this time being 2·2 per stem.

The yield figures confirmed the result of the previous experiments that a large increase could be obtained by means of a single application of insecticides.

Aphid counts at weekly intervals showed that the best insecticides, Systox (0·05 per cent active ingredient), Parathion (0·02 per cent w/v.), and Nicotine (0·1 per cent alkaloid), by effectively destroying the primary migrants and their first progeny, prevented build-up of aphids in July. Pyrethrum (0·02 per cent w/v. total pyrethrins) + piperonyl butoxide (0·2 per cent w/v.), and D.D.T. (0·1 per cent w/v.) emulsion though not so effective destroyed most of the primary migrants. In the untreated control plots and in those treated with a 0·1 per cent D.D.T. crystalline suspension

the mean aphid population rose in July to peaks of 1,660 and 2,455 per stem respectively and caused serious damage. Clearly if D.D.T. is required as an aphicide its formulation is important.

The growth of the beans in untreated control plots and in the Parathion treated plots was compared; it was found that the heavy aphid attack had little effect on flower production or flower set. However it prevented many pods from developing to maturity, and reduced the size of seed as well as the yield. Observations were made in the field, and trials carried out in the laboratory on the effect of the different insecticides on Coccinellid predators of the aphids. All except nicotine were toxic as contact insecticides; *Coccinella septempunctata* was less susceptible than *Adelia bipunctata*.

Control of virus vectors

Potatoes. In collaboration with L. Broadbent of the Plant Pathology Department, the department assisted in experiments on the control of potato virus by controlling the insect vectors. One experiment was carried out on the farm of Mr. Soper of Harlow, Essex and another at the farm of Messrs. Tinney and Hitchcock, Clavering, Essex. In the latter experiment the collaboration was extended to Dr. Gough of the National Agricultural Advisory Service and Pest Control Limited. The results of these experiments will not be available until next year.

Brassicas. Two small-scale experiments on the prevention of introduction of Cauliflower mosaic and cabbage black ringspot virus by controlling the aphid vectors were carried out by G. D. Heathcote of the Plant Pathology Department and J. Ward of this department. Systox (0·1 per cent w/v. active ingredient), Pestox iii (0·1 per cent w/v. commercial), Parathion (0·5 per cent w/v. technical), Toxaphene (0·125 per cent w/v. technical), Pyrethrins + piperonyl butoxide (0·01 per cent w/v. total pyrethrins + 0·03 per cent w/v. piperonyl butoxide) and pyrolan (0·1 w/v.) were used, and in the second experiment D.D.T. (0·2 per cent w/v. technical), Pyrolan (0·1 per cent w/v.), Systox (0·1 per cent w/v. active ingredient) and the pyrethrins + piperonyl butoxide (0·03 per cent w/v. total pyrethrins + 0·03 per cent w/v. piperonyl butoxide) were used.

The materials were sprayed in aqueous media at intervals of 10 days starting as soon as possible after the emergence of the seedlings.

In the first experiment the maximum recorded total infection was 3·3 per cent; in the second experiment the maximum recorded was 56·7 per cent. None of the insecticides produced any significant reduction in infection. Pyrolan gave the greatest difference in both experiments with an infection rate of 1·2 per cent in the first experiment and 43·8 per cent in the second experiment.

G. D. Heathcote of the Plant Pathology Department and J. Ward of this department are carrying out an investigation in the greenhouse of the behaviour of aphids towards plants treated with a variety of insecticides to provide data on which to select insecticides for virus control.

ENTOMOLOGY DEPARTMENT

C. B. Williams

The work of the department continued during the year without any major change.

Staff

C. B. Williams was elected President of the British Ecological Society.

H. F. Barnes was invited to visit Eire during July 1952 to report on an exceptionally heavy outbreak of wheat blossom midge, and to discuss future work and control measures with the Department of Agriculture of Eire.

Miss Stokes obtained her degree of M.Sc. at Reading for work on gall midges at Rothamsted. She also visited Holland for two months (June and July, 1952) to study gall midge problems in that country, working chiefly at the Institute for Phytopathological Research at Amsterdam. This visit was arranged as an exchange with Mr. Nijveldt who came to Rothamsted in 1952.

B. Singh completed his work on the problems of insects caught in suction traps near the ground, and was awarded the Ph.D. degree of London University for his thesis. He returned to India in July, 1952.

J. E. Satchell's Agricultural Research Council Scholarship was extended for a third year to enable him to continue work on earthworms.

Miss S. El Ziady came as a post-graduate worker from Egypt for about two years in the department.

Population Conference

In September, 1952, a four-day conference was held in Harpenden on problems of Insect Populations under the auspices of the "Comité Européen d'Etudes de Zoologie Agricole" for which the Entomology Department of Rothamsted acted as hosts. Delegates from abroad came from France (2), Holland (2), Belgium (2), Switzerland (2) and Eire (1), with about 25 British visitors from outside Harpenden and about 25 from Rothamsted and the Ministry of Agriculture Plant Pathology Laboratory. I. Thomas of the Ministry of Agriculture was Secretary, and C. B. Williams was Chairman. Meetings were held on three days and visits were paid to Rothamsted laboratories and to Cambridge.

Effect of Weather Conditions on Insects

(C. B. Williams, B. P. Singh, M. M. Hosni, Samira El-Ziady)

This work continued with ultra-violet light traps working in the Manor Wood and in the Manor garden, and suction traps in these same two localities for comparison, and also at two levels, 5 feet and 30 feet, in the Rothamsted Lodge garden. The ultra-violet traps caught about the same number of insects as the previous

year. An analysis of these results by M. M. Hosni shows a closer relation between insect activity and mean night temperature than between activity and minimum temperature as previously used.

The analysis of the moon's effect on suction traps was continued with conflicting results, as some traps showed a lunar periodicity and others none.

Insect Migration

(C. B. Williams, R. A. French)

Work has consisted chiefly in completion and re-arranging our files of records, which now include over 50,000 cards. A book on the subject is in preparation by C. B. Williams and the manuscript of this is nearly completed.

The Effect of Population Density on Insects

(D. B. Long)

Certain fundamental differences which were found to exist between larvae of Lepidoptera bred in solitary and crowded conditions have been studied in greater detail. Several species examined showed differences in colouration, darker forms being generally found amongst the crowded larvae. The basis of these colour differences has been studied in three species. It was found that the hypodermis carried the colour pattern whilst the pigmentation of the cuticle which appeared to be of a melanin type was superimposed. The pigments of the hypodermis are unstable and a method of reducing the rate of their decomposition has been developed. The pigmentation of the hypodermis and the cuticle appeared to be inter-related and was governed by the condition of culture. In the case of larvae of *Plusia gamma* L., although the colour differences do not begin to appear until the fourth instar, it could be shown that the condition of culture in the early instars did influence the final colour. Variations in the degree of the colour response occurring within crowded cultures of *P. gamma* were shown by the breeding of selected lines to involve a genetic factor.

Crowded larvae had been observed to have a shorter larval duration than their solitary counterparts, taking about 80 per cent of the time of the latter to complete their larval development. It was found in *P. gamma* and *Diataraxia oleracea* L. that about a quarter of this time difference was due to the tendency of crowded larvae to pass through fewer instars. The actual number of instars is most probably directly associated with a rapid rate of development. The lower mortality in the crowded cultures also appears to be associated with the faster rate of development.

These effects coupled with the better mating opportunities afforded by large simultaneous emergences of the imagos in crowded cultures indicate the possible importance of localized population densities in the subsequent population build-up of a multi-voltine species.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes)

The occurrence of the wheat blossom midges on Broadbalk was studied for the twenty-sixth successive year and, as was expected, the infestation was less than in 1951. The percentage grain infestation for 1951 and 1952 was 14·2 and 7·7 respectively.

At the invitation of the Eire Department of Agriculture, a visit was paid during July to inspect the occurrence of the wheat blossom midges in Co. Cork, Co. Waterford and Co. Wexford and to assess the effectiveness of D.D.T. spraying. A report embodying recommendations was submitted to the Department.

The investigations of the swede midge was continued during the summer in the Netherlands by Miss Stokes. Possible discrepancies between the behaviour of the midge there and in England were especially studied. A report of this work has been sent to the Netherlands Institute for Phyto-pathological Research (I.P.O.) for publication.

A survey of the distribution of the new Shasta Daisy flower pest, *Contarinia chrysanthemi*, on wild Ox-eye Daisy was initiated with the co-operation of the entomologists of the National Agricultural Advisory Service and others. As a result it has already been established that this midge occurs in fourteen English counties, south of a line from the Wash to the mouth of the Severn and in Anglesey, Caernarvonshire and Cardiganshire as well as Co. Meath and Co. Wexford. Two other gall midges that may attack cultivated chrysanthemums were found to occur in wild Ox-eye Daisy flowers. The biology of these midges is being studied and preliminary experiments to test their host plant range have been started.

Among the more interesting gall midges sent in for identification have been *Asphondylia sarothamni* on ornamental broom being forced for display purposes; *Dasyneura mali*, the Apple Leaf midge, that seems to be on the increase in the eastern counties; *Thomasiniana theobaldi*, the Raspberry Cane midge, from Finland; *Dasyneura brassicae*, the Brassica Bladder Pod midge, from France; *Profeltiella soya*, the Soy Bean Stem Gall midge, from Japan; and *Contarinia sorghicola*, the Sorghum midge, from Uganda.

The gall midge collection, which now contains nearly 8,500 slides has been enriched by named material received from Canada, the United States and Germany.

Aphid Problems

Factors influencing aphid numbers at crop level, and the infestation of crops

(C. G. Johnson, Elsa Haine, L. R. Taylor, B. Johnson)

For the last twenty years weather-induced flight behaviour has been regarded as the most important factor contributing to numbers of aphids in the air. It has been shown, however, that this view may be misleading and that it is the extremely rapid changes in the size of the alate population on the crop, which occur even during the course of a few hours, which are the basic features determining the intensity of the migration over short periods during the day. The

effects of this population change may overwhelm changes in proportion taking flight due to weather. Most dispersal occurs at relatively high winds. What appear to be important now are the weather factors and conditions of crop layout which encourage aphids to alight. Calm weather and shelter is not the prerequisite of migration, as formerly thought, but it is important for the maintenance of those high concentrations in the neighbourhood of plants which is so significant in virus transmission.

B. Johnson is studying the flight of aphids with reference to the factors which determine the frequency, duration and cessation of flight. This links with the work mentioned above and also with the deposition of aerial populations being studied, in collaboration, at Cardington and at Sutton Bonington.

A detailed study was made in 1952 of the three most important phases which, as the above work has shown, lead up to migration. In this work Dr. E. Haine has collaborated actively. These three phases are the moulting periodicity underlying the rhythmical production of alatae, the duration of the pre-flight period before migration during which the aphids mature but will not fly, and the actual departure by flight. The first two appear to have more influence on the timing and intensity of migration than the last.

Dr. Haine is investigationg factors which determine the rhythmical sequence of alate production.

The investigation of infestation patterns on bean fields in relation to wind direction continues in collaboration with Mr. C. E. Taylor of Sutton Bonington.

In the problem of wind dispersal of aphids our suction traps for use on barrage balloons at Cardington have been redesigned and remade. One of the greatest difficulties in investigating aphids occurring at high altitudes is to sample enough air to obtain a sufficient number of aphids for statistical analysis. The larger the suction traps the fewer can be carried by the balloon to a desirable height. To overcome these difficulties two very large light-weight traps are being constructed. The Royal Society has given a grant of £100 towards this.

Data from Cardington from the four past years is being analysed.

The natural enemies of aphids (C. J. Banks)

The preliminary observations on the predators of the Black Bean aphid, *Aphis fabae* Scop., carried out in 1951 have formed the basis of further studies in 1952. Special attention was paid to the population changes of Coccinellidae which were particularly abundant.

Populations of these in their overwintering quarters, on stinging nettles and on three experimental bean plots, were investigated.

There were large fluctuations of numbers on the bean plots and it was possible to associate these with the parallel changes on the nettles; information obtained from the numbers caught in two suction traps was of especial value in this connection.

Populations on the three plots varied considerably during the 8–9 weeks of the infestation by the aphid, both within and between

plots, but showed a close correspondence of egg numbers with the populations arriving from overwintering quarters and from the nettles. Larval populations of the plots also showed marked differences between plots but they could be reduced to a common type, the variations from week to week being largely caused by fluctuations in the numbers of eggs laid the week before.

The female beetles usually lay their eggs at random and the adults themselves may be distributed at random on the bean stems. The emerging larvae are, therefore, frequently in unfavourable positions for food and, when their population density is high, resort to cannibalism. Destruction of the eggs by the larvae was a common phenomenon on one of the plots which was conspicuous for its high density of all stages of Coccinellidae.

Work on Syrphidae was also continued. The non-random distribution of eggs and larvae of these Diptera, noticed last year, was confirmed by the field work of 1952. Unlike the Coccinellidae, female Syrphidae tend to lay their eggs on the most heavily infested stems and often among the aphid colonies, with the result that the emerging larvae are well supplied with immediate food. The abundance of various species of adult Syrphidae flying over bean plots during the spring and summer was estimated by the use of the suction traps and an attempt has been made to associate these numbers of adult flies and of eggs and larvae with the populations of aphids.

In confirmation of similar work of 1951, it was observed that the aphis infestations were well established at a time when adult Syrphidae were scarce in the traps and by the time that the flies had once more become adundant, the infestations by *A. fabae* were almost over. It is probably significant that in the three plots, high aphid numbers were associated with low larval populations.

Soil Arthropod Problems

Agriculture (F. Raw, J. W. Stephenson)

The wireworm population studies on the ley and arable experiment on Highfield and Fosters have been continued. Samples were taken in March and September 1952 and their examination has again formed a major part of the year's work. The results to date reveal two important features of the build-up of wireworm populations in leys.

1. Starting from the low population resulting from three years' arable cropping wireworm numbers can rise during three years under grass to a level at which damage to crops would follow ploughing up.

2. Under similar circumstances there appears to be relatively little build-up of population during three years under lucerne. Unfortunately because of the use of D.D.T. to control weevils on some of the lucerne plots, all the plots could not be included in these observations.

The rapid build-up under grass is of interest because it was generally supposed that build-up from old arable conditions would be slow and farmers using short leys might thereby avoid wireworm attacks. We still know very little about the behaviour and move-

ments of adults in the field and the extent to which build-up of population depends on oviposition by adults emerging within the field or by adults migrating from surrounding fields. In the ley and arable experiment with small contiguous plots migration may be considerable.

The small build-up under lucerne is of particular interest as it substantiates farming experience which has tended to show that wireworm attacks following lucerne leys are unusual. Where farmers wish to take potatoes as their first crop after a ley, and where chemical control is precluded, lucerne leys may be valuable.

In collaboration with the Insecticides Department a follow-up of the 1947–50 experiments on chemical control of wireworms has been started. The new experiment is designed to test the direct and residual effects of aldrin, chlordane, B.H.C. and D.D.T. in winter wheat. There was some difficulty in finding a suitable site and five fields on the farm were sampled before a site in Geescroft was selected. The initial wireworm population of the field while still under grass was approximately 2½ millions per acre. During 1952, the first year out of old grass, the wireworm attack was slight and at harvest no significant difference in yield between treated and control plots was recorded.

Park grass

The study of the distribution of arthropods in selected Park Grass plots representing varying environmental conditions has been continued and progress has been made in the difficult task of identifying certain groups.

Of the various factors with which it has been sought to correlate insect abundance, pH has attracted most attention. It is felt, however, that other physical or biotic factors correlated with pH rather than pH itself are the operative factors in determining insect abundance. For example mycetophylid larvae (*Sciara* sp.) are very abundant on the extremely acid plots but their abundance is presumably linked with the increased fungal activity under such acid conditions rather than with acidity itself. Other insects, e.g. Protura, are more abundant on the alkaline plots but the reason for this is still obscure. Our work to date has emphasized the need for further work on the biology, and in particular the feeding habits, of many of the insects and also for further surveys of insect distribution in relation to soil types and conditions for comparison with the Park Grass plots.

Earthworms (J. E. Satchell)

In April 1952 selected plots on Park Grass were again sampled by the electrical method. The population estimates obtained agreed closely with those of 1951 and an account of this work is in the course of preparation for publication.

The relationship between the six most abundant species and various physical and biotic characteristics of the plots was studied. The percentage in the total flora of *Agrostis vulgaris, Dactylis glomerata* and Leguminosae gave significant simple regressions on most of these species but this was largely an indirect effect of soil pH. No connection between earthworm populations and the mois-

ture content of the plots was found. The most densely populated plots are those receiving organic manure but owing to the lack of an appropriate method of chemical analysis, the effect of soil organic matter on earthworm populations could not be demonstrated.

The regressions of pH on *Allolobophora caliginosa, Eisenia rosea, Lumbricus castaneus* and *Lumbricus terrestris* were highly significant but on *Allolobophora nocturna* and *Octolasium cyaneum* they were not significant.

Earthworms kept in the laboratory would not enter soil from the most acid plots and over a critical range, six species, including *A. nocturna* and *O. cyaneum*, were sensitive to changes of pH 0·2 in acidity of aqueous solutions.

The soil acidity complex, in relation to its effect on earthworm populations, is being further investigated.

Forestry (P. W. Murphy)

Considerable progress has been made in the examination and analysis of samples obtained in previous years. It is now possible to give a broad outline of the faunal population occurring in natural and cultivated heathland. The table contrasts the total population of arthropod organisms in natural heathland with that occurring in cultivated heathland planted with Sitka Spruce (trees 20 years old and forming canopy). These populations represent 570,000 and 835,000 individuals per square metre respectively, or 2,300 and 3,380 million per acre. The population in the natural heathland is concentrated in the surface layers, 96 per cent of the total being present in the first 2¼ inches of the profile. The cultivated heathland with trees shows two zones: the litter layer on the surface where 40 per cent of the population occurs and the raw humus "sandwich" formed in the "ploughing" process which contains 54 per cent of the population.

Qualitative structure of the arthropod fauna occurring in heathland

Sample type	Total population per sample (500 cc.)	Acari	Collembola	Other arthropods
		%	%	%
Natural Heathland ..	998	95·2	3·8	1·0
Cultivated Heathland plus Sitka Spruce ..	1462	90·5	8·1	1·4

The qualitative structure of the population is indicated in the table, the most striking feature being the preponderance of Acari in both habitats. However, owing to the great variations from sample to sample, these figures should be regarded merely as broad indications. The Collembola figures are particularly subject to violent fluctuations from sample to sample and it is probable that they are here represented by minimal values.

In the 1950–51 report attention was drawn to the occurrence of a species of the Acaridiae in natural heathland. This mite (*Schwiebia* sp.) is of interest because although forming only 5 per cent of the total population, its distribution shows a marked zoning in the profile. There tend to be two peaks, one in the lower part of the raw humus horizon (just below the main faunal concentration)

and the other in the organic material above the pan. At the second level this mite is virtually the only arthropod representative.

The main laboratory work in connection with an experiment designed to test the effect of various methods of sample preparation for extraction in modified Berlese funnels has been completed. The principal methods tested were (1) undisturbed samples of various depths, (2) disturbed samples, (3) sample orientation, and (4) effect of sample storage.

At the same time an effort was made to relate population movement to moisture content of sample. At the time of writing the experimental data have not been analysed, but the following more obvious preliminary findings may be mentioned:—

1. The tendency for the arthropod fauna (except some predatory species) to remain in the sample until a certain critical moisture content is reached.

2. Larger populations were recovered from undisturbed samples $\frac{1}{2}$ in. deep, than from those of greater depth.

3. Much larger populations were obtained from undisturbed than disturbed samples, though it is interesting to note that one or two species recovered from the latter samples were rarely present in the undisturbed samples.

4. Sample storage (at room temperature) had a somewhat deleterious effect on the populations recovered though the effect was not as marked as one would expect.

5. Extraction with the funnel air temperature 30–35°C was more efficient than at room temperature.

It should be stressed that these results were obtained with *Calluna* heathland samples, and do not necessarily apply to other habitats.

BEE DEPARTMENT

C. G. Butler

General

As in previous years members of the department have given lectures and demonstrations at meetings of Scientific Societies, Beekeepers' Associations and other organizations, have served on various Committees, and have assisted with an Extension Course on "The Honeybee and some other Social Insects and their Allies", which was organized by London University.

C. G. Butler and C. R. Ribbands attended the meeting of the British Association in Belfast and read papers; a short film made by Mr. C. P. Abbott, in collaboration with C. G. Butler and J. B. Free, illustrating certain aspects of the behaviour of bees at the hive entrance, was also shown.

During the spring G. Raw (née Wykes) spent a few weeks at the Bienenabteilung of the Liebefeld Institute, Bern, demonstrating the technique for the quantitative analysis of nectar sugars by paper partition chromatography.

During the past year the research work of the department has been continued along the lines that have been outlined in previous reports, and a good deal of attention has been paid to tidying up some of the loose ends of previous work and in attempting to apply the information that has been obtained to specific practical problems.

In the past experience has shown that, largely on account of a lack of sufficient information regarding the sense physiology and behaviour of the honeybee, it was not possible to attempt to solve in a rational manner many of the problems with which seed growers and practical beekeepers are faced. To-day we possess much more of this fundamental information and it is intended that a much higher proportion than hitherto of the time of members of the department shall be devoted to the solution of particular problems in pollination and also in practical beekeeping. There are two ways in which many of the problems of practical beekeeping can be tackled. One is to make comparative tests on a very large scale of different methods of management, the other is to study the fundamental nature of the aspects of behaviour concerned and then, on the basis of the information obtained, to devise or select suitable practical methods of management. It is necessarily the second of these methods which is employed in the Bee Department.

Bee Behaviour

Division of labour

C. R. Ribbands has published the results of his work on the division of labour amongst the worker bees of a colony (132). He reached the conclusion that age plays only a subsidiary rôle in determining the occupation of each worker, and that the available food supplies determine the proportion of the total population of its bees that is required for each task. This presupposes extensive food sharing amongst the bees of a colony resulting in its adult

members fitting their occupations to suit the requirements of their colony at any given time.

The extent to which food sharing does in fact occur has been investigated by C. R. Ribbands in collaboration with H. L. Nixon of the Plant Pathology Department (131), a radio-active tracer technique being used. It was found that within 27 hours of a single tablespoonful of sugar syrup containing a radio-active tracer being carried by six marked bees into the hive of a large colony, half the bees of the colony had received a share of this small quantity of syrup. The conclusion was reached, therefore, that food sharing takes place very quickly and thoroughly. It is hoped that it may be possible to carry out more detailed experiments on this subject, which clearly has an important bearing on the distribution of certain toxic substances which are sometimes collected by foraging bees and on the distribution of drugs fed to colonies in attempts to control disease, should more sensitive apparatus become available.

Recognition by bees of members of their own colony

In 1926 Professor K. von Frisch and Dr. G. A. Rösch showed that when foragers from a colony find a dish of concentrated sugar syrup and start to feed upon it they expose their Nassanoff, or scent-producing organs, and that the scent thus produced serves to attract other foraging bees to the source of food. Furthermore, although the scent produced is attractive to all bees it is more attractive to other members of the scent-producing bees' own colony than to bees from other colonies. Thus these workers demonstrated that bees can distinguish between members of their own colony and bees from other colonies by scent. Dr. H. Kalmus, of University College, London, and C. R. Ribbands have now successfully repeated and extended this work (130). They have shown that bees are not attracted by the sight or sound of other members of their colony, but rather by their scent. Each colony possesses its own particular odour which is shared by all its members. This colony odour is not hereditary but is derived from the food supply in use by the colony at any given time and shared by all its bees. Since the food supply of each colony differs in some degree from those of other colonies, each colony in an apiary is likely to posses an odour which is slightly different from that of other colonies. Clearly such distinctive colony odours play an important part in enabling the members of a colony to distinguish between friend and foe and thus to defend their hive against intruding bees from other colonies.

C. R. Ribbands and N. Speirs are now engaged in reinvestigating the activity of the olfactory sense of the honeybee and her ability to discriminate between mixtures of scents. They have already been able to show that the bee's abilities in these directions are greater than the results of previous work have indicated.

C. R. Ribbands and N. Speirs have also carried out some experiments on the reorientation of honeybees at the hive entrance; marked bees of known ages were used. The bees reorientated quickly and completely in these experiments, and age had no effect upon their adaptability. Once again colony odour played an important part in this reorientation.

Swarming

J. Simpson has continued his study of the fundamental processes involved in swarming. Throughout the past season groups of colonies were treated in three different ways in attempts to induce them to swarm: (1) Very large quantities of sealed brood were given resulting, temporarily, in a considerable increase in the proportion of young bees in the colonies. (2) All eggs and unsealed brood were removed. (3) The bees were severely crowded by reduction of the space within their hives. Some, but not all, of the colonies in which the bees were severely crowded made attempts to swarm; none of the colonies subjected to the other types of treatment showed any inclination to do so. This variability in the behaviour of the bees of the overcrowded colonies may, perhaps, be explained by genetical differences, or, alternatively, may indicate that although overcrowding is a predisposing factor it is not the only condition necessary to induce swarming. According to Gerstung's brood food theory swarming results from the efforts of the bees of a colony in which there is an excess of bees of nursing age to find an outlet for the surplus brood food they produce by rearing queens. However, the failure of the treatment in which the experimental colonies were flooded with young bees—i.e. bees which normally produce brood food—to cause swarming is strong evidence against the correctness of this theory. No sign of any surplus brood food was observed in these colonies. Furthermore in the case of those colonies in which attempts were made to remove all eggs and unsealed brood an occasional larvae was overlooked and such larvae appeared to be receiving abnormally large amounts of brood food; nevertheless none of these colonies made any attempt to swarm.

Bumblebee behaviour

J. B. Free has continued his work on the behaviour of various species of bumblebees in an attempt to determine their efficiency as pollinating agents, particularly of red clover.

A comparison is also being made of the relative efficiency of honeybees and various species of bumblebees in this connection. If it be found that the bumblebee should be used in preference to the honeybee as a pollinating agent for red clover it will be desirable that we should know much more than we do about the foraging behaviour of the various species and of the economy of their colonies.

J. B. Free has commenced to study such aspects of bumblebee behaviour as the size of the foraging areas of individuals; their constancy to particular crops; the nature of the division of labour; and the orientating abilities of foraging bumblebees when their nests are moved to new sites; and has made some useful progress.

Should it prove to be desirable to attempt to increase the number of bumblebees in particular areas for purposes of pollination, this will have to be done either by providing suitable nesting sites, etc., or by moving captive colonies maintained in nest-boxes to those areas. J. B. Free has obtained some degree of success in experiments both with artificial nesting sites and in inducing overwintered queens to found colonies in captivity. However should

it prove desirable to use bumblebees for the pollination of certain crops, considerable work still requires to be done before it will be known whether or not either of these methods are likely to prove practicable in the field.

Nectar secretion

G. Raw has, with the help of E. Carlisle, continued her quantitative investigations of the different sugars present in nectar. The fructose/glucose ratio, which is known to influence the tendency of honeys to granulate, was found to vary widely in the nectars of the flowers of the twelve species examined. The results suggest that the relative proportions of sucrose, glucose and fructose normally tend to remain constant in the nectar of any given species, but further work is required before any definite conclusion can be reached.

M. Ryle has continued her work on the effect of fertilizer treatment on nectar secretion in red clover. G. Raw has taken the opportunity of using the plants in this experiment to investigate the possible influence of fertilizer treatments on the sugar composition of the nectars produced.

Thanks to the kind co-operation of the Director of East Malling Research Station and his assistants, M. Ryle, with the help of E. Carlisle, has been able to study the secretion of nectar by apple trees under different fertilizer treatments. The results obtained showed that extra potash significantly increased the mean quantity of sugar produced per flower. They also suggested that phosphate increased it, but that nitrate decreased it provided that adequate potash was present. The highest mean yield was obtained from trees receiving phosphate and the higher dose of potash but no nitrate. It was one-and-three-quarter times the lowest mean yield which was from trees receiving no phosphate and the lower dose of potash (nitrate having no effect). It is concluded that increase of nectar yields of apple trees by means of fertilizer treatments and, therefore almost certainly, an increase in their attractiveness to nectar-seeking pollinating insects, is a practical possibility.

General Research

Pollen supplement trials

C. G. Butler, E. Carlisle and J. Simpson have completed in the Rothamsted apiaries a series of tests of the value of pollen supplement feeding towards increasing the amount of brood reared by colonies of bees in the spring. These trials have been carried out during the years 1949–52, the principal mixture fed consisting of soya flour with dried brewer's yeast. The results, as shown in the following table, indicate that the increase in the amount of brood produced (the long-term effect of which has yet to be assessed) varied considerably from year to year. It probably averaged at least 100 per cent in 1951 but may have been negative in 1952.

Mean area of sealed brood (sq. ins.) in colonies in pollen supplement trials

Year	Control	Soya-yeast mixture	Difference required for significance (P=0·05)
1949 and 1950	124	201	24
1951	145	312	24
1952	539	513	84

Honey stomach contents of pollen gathering bees

Observers of foraging bees in the field have claimed to be able to distinguish between bees gathering pollen and nectar and those gathering pollen only by comparing the translucencies of the spots produced by absorbing on filter paper the contents of the bees' honey stomachs as a rough measure of sugar concentration. It was assumed that bees gathering pollen only would take out honey from the hive and that this would have a higher concentration than the nectar carried by bees gathering both pollen and nectar. J. Simpson and C. G. Butler have now shown that this procedure is useless since the range of sugar concentrations (measured by refractometer) found in the honey stomachs of bees working crops, such as poppies, yielding only pollen is similar to that of nectar. The alternative possibility that consistent differences in translucency might result from the greater proportion of sucrose in nectar than in honey was eliminated by a comparison of honey diluted to the concentration of average nectar with a pure sucrose solution of the same concentration.

Queen introduction

The problem of introducing virgin or laying queens to colonies of bees has been recognized as an extremely important one. Although many methods are known, some of which often give satisfactory results, we cannot hope to be able to introduce queens without loss or damage until we can forecast the behaviour that will take place when any given queen is introduced to the members of any given colony, whatever the condition of the queen and colony may be, as we shall not know how to set the stage in such a way that both bees and queen will welcome one another.

A strange queen is no more than an intruder, welcome or otherwise, when she is introduced to the bees of a colony other than the one in which she was reared. It will obviously be an advantage, therefore, if, before one begins to experiment with queens, one obtains some information on the way in which the worker bees of a colony respond to intruding workers from other colonies. This latter problem has been investigated by C. G. Butler and J. B. Free and a paper prepared on the subject (128).

It was found that honeybees do not normally guard the entrance of their hives and examine incoming bees of any kind unless their colonies have been alerted in some way, such as by the presence of numbers of strange bees. They are much more readily alerted during a nectar dearth and tend to give up guard duties when nectar is abundant. Should numbers of strange bees attempt to enter

the hive of a really alert colony mass fighting sometimes takes place between the excited guards of the colonies concerned and many bees are killed. Normally, however, such a high degree of excitement does not occur and only robber bees which try to enter alert colonies are attacked, unwitting intruders being examined and, on being recognized as intruders by their strange body odours, mauled and dragged away from the hive entrance but not stung. Such unwitting intruders often adopt a submissive attitude towards the guard bees, remaining more or less passive whilst being examined or mauled. When the guard bee approaches the head of such a submissive intruder the latter offers her a drop of food between her open mandibles. Usually such offers of food are refused and after several refusals the submissive bee extends her tongue and commences to " strop " it with her forelegs. It is believed that this is a " displacement activity " released by the frustration of the submissive intruder's urges to give food and to enter the hive.

Bees suffering from a form of " bee paralysis " have also been seen to be examined and mauled by guards of their own colony, presumably on account of some strange body odour resulting from disturbance of their metabolism. Such bees assume a submissive attitude and are often dragged away from the hive entrance.

Even when guards are present a few intruders succeed in entering the hive where they are subjected to further examination and mauling, often being dragged out of the hive. Those that succeed in remaining within the hive for two or three hours appear to be adopted by the colony having, presumably, acquired the colony odour. Such accepted bees have been seen twenty-four hours after first entering the hive of a strange colony guarding its entrance against further intruders from their parent colony.

Undoubtedly all the factors which influence colony alertness play an important part in determining the ease or otherwise with which colonies can be united together, or strange queens introduced to colonies. In preliminary work with queens C. G. Butler has found that queens will sometimes adopt a submissive attitude towards guard bees and even offer them food just as submissive workers do. It has also been found that when a queen is " balled ", the bees forming the " ball " around the queen will often sting one another in their attempts to sting the queen. Furthermore, some of the workers that have been " balling " the queen are themselves " balled " by other members of their colony when they leave her. This suggests that the scent of the queen is transferred to the bodies of some of the workers " balling " her and serves to excite the other bees to attack bees contaminated with the queen's body odour. Experiment has shown that this theory is correct, and some evidence has also been obtained which suggests that the bees of a colony recognize the presence of their own queen, although they may be in a remote part of the hive, by her odour adhering to the bodies of some of the workers that have recently been with her. In this simple way, perhaps, all the bees of a colony are able to detect the presence or absence of their queen; however, further work will be done in order to establish this probability.

Pollination of red clover

The acquisition of four plastic-screen cages has enable C. G. Butler, E. Tyndale-Biscoe, J. B. Free and J. Simpson to begin investigations on the relative efficiency of honeybees and " robbing " and " non-robbing " species of bumblebees as pollinators of red clover. A good deal of work has also been done in attempts to induce honeybees to work red clover flowers for pollen or nectar, and also to increase the amount of pollen collected by colonies by robbing the returning foragers of a high proportion of their pollen loads, a specially designed trapping-screen being used for this purpose. Unfortunately no useful increase in foraging (pollinating) activity has been obtained with any of the methods so far tried.

Bee Diseases

Nosema disease

L. Bailey has devoted a good deal of time to checking and extending the investigations of Dr. H. Katznelson and Dr. C. A. Jamieson of Canada, upon the effect of the new antibiotic " fumagillin " on the infection of worker honeybees by *Nosema apis*.

He has found that this drug prevents the establishment of this disease within the ventricular epithelium and also may cure the heavily infected bee within a short space of time by suppression of the spread of infection already present and the sloughing away of the diseased tissue by the natural generation of the epithelium. The lowest effective dose of the drug seems to be about 1 mgm. per 100 mls. of syrup fed freely.

Large-scale field experiments are now being carried out with the drug which appears to offer high promise of providing an efficient treatment for this widespread and serious disease.

Very promising results have also been obtained in attempts to eliminate this disease from colonies in the field by transference of bees to clean comb foundation.

European foul brood, acarine disease, etc.

H. Finegan has continued the work on E.F.B. commenced by Mrs. Schreiner. In particular attempts are being made to culture

Bacillus pluton.

A number of Gram-positive organisms, very similar in appearance to *B. pluton* have been isolated and have been tested for pathogenicity on honeybee larvae reared artificially outside the hive. This technique allows of much better control than do similar trials with larvae in the hive.

J. Simpson, in collaboration with F. A. Skinner of the Soil Microbiology Department, has carried out further tests to determine the practical value of a yeast-like organism, *Acaromyces laviae*, which is apparently capable of destroying the parasitic mite, *Acarapis woodi*, which is responsible for acarine disease in bees. Mention has already been made in the section of this report dealing with experiments on queen introduction of observations that have been made on the behaviour of the worker bees of a colony towards members of their colony suffering from bee paralysis.

Bee Breeding

Work has been continued on this subject and, thanks to the generosity of the Reverend Brother Adam of Buckfast Abbey, who is collaborating with us in a study of the characteristics of the honeybees of Europe and the Middle East, a unique collection of bees from apiaries in these parts of the world has been built up during the last two or three years. These are being carefully examined and described and it is hoped to obtain a detailed picture of the material available for use in attempts to improve our present strains of bees.

STATISTICS DEPARTMENT

F. YATES

DESIGN AND ANALYSIS OF EXPERIMENTS

The department has continued the design and analysis of field and laboratory experiments for Rothamsted and other research stations, and for the National Agricultural Advisory Service. The analytical work has again involved a very considerable computing effort. Members of the staff attend meetings of the National Agricultural Advisory Service Provincial Experiments Committees, and the department is regularly represented on committees responsible for co-ordinating the National Agricultural Advisory Service's experimental work and that of the Experimental Husbandry Farms.

An interesting piece of work in the animal husbandry field was the organization of a co-operative experimental programme on the effects of feeding antibiotics to pigs. This was undertaken at the request of the Agricultural Research Council, and the planning, supervision, analysis and reporting represented a joint piece of work by J. Wardley-Smith, of the Agricultural Research Council Secretariat, R. C. Cambell of the Agricultural Research Council Unit of Animal Reproduction and M. H. Westmacott of this department. Experiments were carried out at six Research Stations, Agricultural Colleges, Experimental Husbandry Farms, etc. The undertaking marks a step forward in the organization of simultaneous co-operative trials on urgent practical problems in animal husbandry.

F. B. Leech, with the assistance of D. H. Rees, has analysed the results of a large-scale field experiment on the feeding of iodinated casein and thyroxine to cows (159). Earlier work had led to the belief that the feeding of these thyroid-stimulating substances might substantially increase milk yield, but the effect of their long-term use on the health of the cows was unknown. In the present experiment there seemed to be no adverse effects on the health of the treated animals, but the effect of the treatment on milk yield was very small, the increase during the period of the treatment being largely counterbalanced by a decrease in the length of lactation.

Although the principles of design and analysis of short-term agricultural field trials are by now well-known, other biological data often present new problems of analysis. H. D. Patterson has collaborated in the interpretation of the results of a set of experiments to determine whether a fragment of ovarian tissue in the rat can generate new oocytes after the rest of the ovary has been removed (148). Patterson has continued to work on the problems of long-term agricultural experiments, and has published a paper on experiments with a fixed rotation of crops (149). In this paper he has analysed eighteen years' results from the Rothamsted 3-course experiment on the effects of ploughing in straw. Healy (144) has described methods of analysis for lattice experiments in which the results for one variety or treatment are missing, a situation that occurs fairly commonly in plant-breeding work. M. H.

Westmacott and W. J. Lessells have begun a study of techniques in grassland experiments.

In an article in *Nature* (150), F. Yates has raised a problem of great practical importance, namely how to make a rational decision on the number of experiments to be carried out on some topic of economic importance. In agricultural research, two situations commonly arise; a new treatment (such as the feeding of antibiotics to pigs) is suggested, and it is necessary to find out whether its application will be economically advantageous to farmers, or it may be required to find the most economic level of a certain treatment (such as a fertilizer dressing) which will be applied anyway. The second problem is the more tractable, and is dealt with in the *Nature* article. Taking sugar beet as an example, it is shown that, in order to determine optimum fertilizer dressings to be applied in all beet-growing areas, a yearly programme of sixty experiments, possibly falling to forty experiments after a few years, is economically justified. A programme averaging twenty-two experiments a year was in fact carried out between 1933 and 1949, and as many farmers do not follow the recommendations emerging from the experiments at all closely, this programme was probably at about the correct level. However, a more realistic aim was that of investigating differential responses in relation to soil analyses and soil type, and it was in fact shown that, for example, the use of nitrogen for sugar beet on fen soils was not an economic proposition. If the farmers who at present apply nitrogen on these soils refrained from doing so they would save about £25,000 annually, about twenty times the annual cost of the experiments. Very large economic gains can be expected from experiments with this broader aim in view, and a much larger programme would certainly be economically justified. The importance of this investigation is underlined by the fact that the sugar beet experiments are unique in British agriculture. On no other crop is there any adequate series of experiments on representative sites for which soil analysis and soil type data are recorded. Similar considerations must apply in very many fields besides agriculture.

The other problem, that of deciding whether to apply some kind of all-or-nothing treatment, is a good deal more difficult, raising a number of interesting points of statistical theory. F. Yates, P. M. Grundy and D. H. Rees are at present working on this topic. The investigation requires some very heavy computing, but some results of considerable interest have already been obtained.

Surveys and Operational Research

The main surveys dealt with during the year were the Survey of Restored Opencast Coal Sites and the Survey of Fertilizer Practice. The former survey was undertaken at the request of the Ministry of Agriculture in the hope of being able to assess the relative merits of different methods of restoration. Whilst the survey did suggest that different methods of restoration substantially affected the subsequent productivity, the results of the survey as a whole were disappointing, and it proved impossible to obtain clear answers on many of the points that had been raised (156, 157).

The Survey of Fertilizer Practice was carried out in ten districts, and a report on eight of these has been issued (158). The survey showed, amongst other things, that the large apparent decline in fertilizer consumption between 1950 and 1952 was due in part to decline in stocks held by farmers and merchants. The estimated figures (1,000 tons) for nitrogen, phosphate and potash are as follows:

	N		P_2O_5		K_2O	
	Supplies	*Consumption*	*Supplies*	*Consumption*	*Supplies*	*Consumption*
1949-50	213	208	461	435	234	219
1950-51	211	202	427	411	225	216
1951-52	182	202	275	335	182	206

B. M. Church has brought together the results of some recent surveys in two papers (141). These are largely based on eight districts surveyed in 1944–45 and again in 1950. Trends in fertilizer consumption are examined, and it is shown that there are possibilities of increased production by the more general use of fertilizers on cereals, fodder roots and grassland.

G. V. Dyke and P. R. D. Avis have continued to work on the results of the Survey of Maincrop Potatoes, 1948–50. A paper discussing the yield figures is completed, and two further papers are in preparation dealing with the forecasting of final yields and with growers' practices. J. K. R. Wood has carried out theoretical investigations on different methods of estimation for this survey as part of his work for a Ph.D. thesis. F. B. Leech and B. M. Church are co-operating in the planning and analysis of a survey of animal diseases carried out in Surrey and Berkshire during the past three years by F. W. Withers (161). Other surveys include a survey of farm tractor utilization carried out by J. K. W. Slater of the National Institute of Agricultural Engineering in consultation with members of this department (160), and a survey of rabbit damage to winter wheat, supervised by M. H. Westmacott and G. V. Dyke.

Work has continued on the summarization of existing knowledge on agricultural problems. With members of other departments, D. A. Boyd has written a paper (140) on the manuring of field beans, based on experiments carried out at Rothamsted or organized from there. They show that a moderate dressing of farmyard manure ploughed in is an excellent form of manuring for this crop; in the absence of F.Y.M. the main need is for potash, phosphate dressings being usually not economic. A PK fertilizer placed in bands near the seed was twice as effective as the same fertilizer broadcast, and quite small dressings were adequate if applied in this way. High seed rates (up to 3 cwt. per acre) and early sowing were both advantageous. A similar paper by D. A. Boyd and W. J. Lessells on the effect of seed rate on the yield of potatoes is also completed.

A second edition of Sampling Methods for Censuses and Surveys has been prepared by F. Yates and is expected to appear during 1953. The results of several recent theoretical studies have been included. An important problem is that of estimating variances when the domains of study cut across the strata of a stratified

sample; a paper on this subject is being prepared by H. D. Patterson and J. K. R. Wood.

It was decided during the year to abandon work on the Precision Wheat Records, obtained before the war with a view to elucidating the effects of weather factors on crop yields. The work already carried out on these records has shown that no further useful results are likely to be obtained.

Colonial Work

The department continues to assist workers from all parts of the Commonwealth with statistical problems. Most of this work is handled by G. E. Hodnett, the Colonial Office statistician. Twelve colonial workers have stayed in the department for periods up to eight weeks, and nineteen others have paid brief visits.

Hodnett has also summarized the results of twenty years' experiments on sugar cane in Trinidad (146) deriving standard responses to N, P, K and organic manures and relating these to soil factors. He has now completed a similar analysis for British Guiana. He has also analysed a uniformity trial on groundnuts carried out by the Overseas Food Corporation in Tanganyika (147). This experiment gives some guidance on the best shape and size of plot for use with this crop, and enables comparisons to be made between various alternative experimental designs.

Other Work

M. J. R. Healy has continued his work in the field of anthropometry and human biology. In a paper (144) read before the Research Section of the Royal Statistical Society he has discussed the conduct and analysis of large-scale anthropometric surveys. The processes of analysis involve well-known statistical techniques, but their application needs more care than is sometimes realized. In the collection of the data, an appreciable proportion of measurements are frequently wrongly recorded and methods are described for avoiding this situation, or of dealing with it when it arises. Data of this kind form a useful proving ground for trying out techniques of multivariate analysis; the development of such techniques has hitherto been guided more by mathematical elegance than by practical considerations. One stumbling-block is the very heavy computing involved—punched card machines are valuable in this field, but are by no means a satisfactory solution to the problem. A similar statistical problem has arisen in connection with the fossil anthropoids discovered during recent years in South Africa. Claims have been made that the teeth of these fossils resemble those of man more nearly than those of the existing great apes. A closer statistical examination of these claims is being made in collaboration with Professor S. Zuckerman. Measurements are available for fairly large series of human and apes' teeth, and an adequate treatment of the data should be possible. Preliminary results appear to show that little useful discrimination can be achieved by means of the usual metrical characters of the teeth.

Healy has also collaborated with M. A. Watson of the Plant Pathology Department in the analysis of field data on virus infections of sugar beet relative to aphis abundance (87). A simple

mathematical model was set up to describe the spread of infection by the aphids, and was found to give a remarkably good explanation of the figures. P. M. Grundy has continued to work on the mathematical aspects of the work of the Entomology Department on insect populations. He has published a paper (142) on the fitting of a normal distribution to grouped data when detailed observations from one tail of the distribution are not available. With F. B. Leech, he has modified a nomogram proposed earlier by M. J. R. Healy for the analysis of biological assay with a quantitative response (144). The investigation shows that in one important type of assay the nomographic method is almost 100 per cent efficient; a recent theoretical advance by Finney is shown to have important practical implications.

The fourth edition of Statistical Tables for Biological, Agricultural and Medical Research was sent to the press during the year. Some new tables are included, and a few errors have been corrected. A good deal of the onerous work involved was undertaken by P. M. Grundy. D. H. Rees has surveyed the recent sampling literature in order to bring up-to-date the bibliography of Sampling Methods for Censuses and Surveys. A start has been made by P. R. D. Avis on the construction of a subject index of recent statistical literature. A scheme for organizing the mechanics of a card-index has been devised and systems of classification for various branches of the subject are being investigated.

Staff

F. Yates visited the United States during June and July. He took part in the conference organized by the North Carolina Institute of Statistics at Blue Ridge, N.C., giving papers on sampling theory and experimental design. M. J. R. Healy and H. D. Patterson attended the summer meeting of the Biometric Society held jointly with the Pharmacological Society in Edinburgh, the former taking part in a question-and-answer session on biological assays. Members of the department gave a two-week course in field experimentation for Provincial Officers of the National Agricultural Advisory Service during February, and took part in a similar course organized by the British Council during May.

M. H. Westmacott has been selected as a member of the 1953 British Mount Everest Expedition.

A. T. Dunn left the department during the year , and G. V. Dyke transferred to the Field Experiments Section. New appointments were N. E. G. Gilbert (from Clare College, Cambridge) and F. B. Leech (from the Veterinary Laboratory, Weybridge). M. E. Davies and J. K. R. Wood were both appointed to the staff on the completion of two years' Ministry of Agriculture post-graduate scholarships, the latter on a temporary basis pending call-up. An exceptionally large number of temporary workers were accommodated during the year—two from Great Britain, twelve from the Commonwealth and five from other overseas countries.

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments: E. M. Crowther (Chairman), H. V. Garner (Secretary), H. H. Mann, J. R. Moffatt, D. J. Watson and F. Yates.

The number of plots handled by the Field Staff at Rothamsted and Woburn were:—

	Grain	Roots	Hay	Grazing	Total
Classical					
Rothamsted	124	72	47	—	243
Woburn	36	—	—	—	36
Long-period experiments					
Rothamsted	335	312	248	96	991
Woburn	133	314	55	12	514
Annual experiments					
Rothamsted	449	569	177	—	1,195
Woburn	8	73	64	—	145
Total	1,085	1,340	591	108	3,124

Considerably more plots were put down in 1952 than in the previous year. This was partly accounted for by some 300 microplots devoted to a preliminary test of a synthetic soil conditioner, and about 250 to small-scale tests of fertilizer placement on beans and other vegetable crops. Some plots were for observation only; the total number of plots actually harvested on the two farms was 2,748.

The weather conditions affecting agricultural operations are described in detail in the farm report; the following brief notes put on record the main features of 1952 to provide a general background for the year's experimental work.

The first two months of the year were much drier than usual, the land was in ideal condition for early spring sowings and most of the spring cereal crops, including Hoosfield barley, were drilled on the last few days of February or the first days of March. The weather then became showery and tilths deteriorated, but there was worse to come, for on 29th March a severe snow-storm occurred with drifts which persisted for nearly a week. This was followed by further showery weather and experimental field work was stopped till mid-April. Roots and potatoes were put in rather late, sometimes on poor seedbeds. Sowings were completed by the first week in May except for barley on Great Field II which followed a failed crop of linseed and was not drilled till 13th May. The weather then became warmer and drier, conditions for growth were very good, and a warm dry spell in June and July, pushed the corn to an unusually early harvest. Spring oats were cut on 23rd July and barley and rye plots were harvested three days later. The plots were got up in very good condition, but before the commercial harvest was complete the weather broke and August had 2·54 inches above the average rainfall, mostly in heavy thunderstorms. Owing to a very wet September and unsettled conditions in October lifting of experimental potatoes continued till the early days of November. A succession of snowfalls and frosts in the last fortnight of the

month further delayed root lifting, leaving a small area of Barnfield mangolds and sugar beet still to complete at the end of the year.

The Classical Experiments

The autumn of 1951 was so wet that Broadbalk was not fit to drill till 5th December in a very poor seedbed, the land being so sticky on the southern side of the field that the seed could scarcely be covered. In spite of this a good plant was found in spring on all plots except plot 10 (nitrogen only) which is usually thin in the section immediately after bare fallow. The first-year effect of bare fallow was less noticeable than usual, but as in the previous year this may have been due to very wet weather. Wild oats, which have now been energetically tackled on this field for several seasons, were abundant by mid-summer but were perhaps not quite so bad as usual. Hand-pulling was once again carried out very thoroughly before the oats had shed and this greatly improved the appearance of the field and increased its value for demonstration purposes. There was little lodging and owing to the catchy weather the crop was harvested rather late and over-ripe.

Hoosfield had an excellent early start, and made an even crop except on certain plots, notably 5A, where acidity is now becoming serious, and also on plot 30 where a slight depression held snow for a long period and seriously damaged the plant. Wild oats were as usual very conspicuous before harvest, so much so that complete hand-pulling was out of the question. The procedure followed in 1946 and 1947 was again adopted whereby the bulk of each plot was cut and carted green before the oats shed, leaving a small area to be hand-pulled and harvested for an estimate yield.

Barnfield carried a good plant and looked somewhat better than usual. There was an exceptional growth of groundsel late in the season on strip AC receiving high nitrogen and in certain areas this topped the plant and probably affected yields. Owing to the wet autumn and snow in late November, lifting was much delayed.

Agdell field which should have carried swedes in 1952 was not drilled, for in recent years this crop has failed entirely owing to severe attacks of clubroot. The future of the Agdell experiment is now under consideration by the Plots Committee.

At Woburn an interesting feature of the Classical experiments was the growth of a winter-sown barley, Pioneer, for the first time on the permanent barley plots. The winter-sown and the usual spring-sown varieties were compared in strips running side by side through the experiment. The winter barley yielded from twice to three times as much as the spring barley alongside. This comparison will be repeated in 1953. The yields are given in the section of the report relating to the Woburn Experimental Station.

Long-Period Rotation Experiments

Ley-arable experiments

In 1952 the experiments on Highfield and Fosters gave the first measurements of fertility differences arising out of cropping with various grasses and legumes over the previous three years. The test crop wheat was excellent on both fields. The crops were clean, stood well and showed differences due to the various pre-treatments. In Highfield the wheat after three years' arable cropping looked the best, but on Fosters lucerne gave the finest wheat crop.

The effect of the higher level of " Nitrochalk " top-dressing was slightly harmful on Highfield, but beneficial on the average on Fosters especially on the straw. The crops following lucerne showed no benefit from nitrogen. The grain yields and the extra effect of the double top-dressing above the single one are given for both fields below.

Ley-arable experiments, Highfield and Fosters, 1952
Wheat, mean yield of grain: cwt. per acre

	After 3 years' cropping with:—				
	Lucerne	Grazed Ley	Cut Grass	Arable Crops	Mean
Highfield					
Mean yield	40·7	36·1	34·1	43·1	38·5
Increase for N	— 3·7	— 1·8	— 5·9	— 1·7	— 3·2
Fosters					
Mean yield	40·5	34·7	36·2	35·3	36·7
Increase for N	0·9	2·3	0·7	3·5	1·8

Potatoes and barley, the second and third test crops were not yet in cycle so merely served to measure the effects of dung and nitrogen. Both crops were more successful on Highfield than in 1952, the potatoes being less damaged by birds and the barley less severely lodged. The potatoes gave a good response to dung on both fields and to nitrogen on Highfield; the residual effect of dung measured in barley amounted to 2·8 cwt. grain in both fields but the direct response to the higher nitrogen dressing was small.

Lucerne in its second and third years became very grassy on Highfield, so much so that the third year yield was affected. Violet root rot noted on certain plots on Highfield in 1951 still persisted.

The grazing plots of permanent grass and leys came on well after the snow of early April and were ready to stock in the third week of this month. At this time all supervisors were fully engaged in completing the arable programme so the grass plots could not then be stocked and the plots had to be mown on 12th May in order to measure the early output and prepare for grazing later. The produce of all hay plots and of the preliminary cuts on the grazing plots were weighed green and sampled for dry matter. The output of the grazed plots was determined from random samples taken with a rotoscythe before every grazing. The mean yields under the various systems of management are given below in terms of hundredweights of dry matter per acre.

Yield of herbage crops, Highfield and Fosters, 1952
Dry matter: cwt. per acre

	Old grass		Reseeded grass		3 year ley		Cut Grass	Cut Lucerne	1 Year Ley
	Hay.	Grazed	Hay.	Grazed	Hay.	Grazed			Hay
Highfield									
Blocks:									
1st year	29·0*	17·9	32·2*	21·8	—	35·7	46·0	44·5	66·0
2nd year	11·9*	26·7	24·2*	27·3	27·3*	26·1	59·8	81·5	—
3rd year	52·4	13·9*	67·1	17·0†	27·5*	20·7	53·3	68·7	—
Fosters									
Blocks:									
1st year	—	—	18·9*	23·6	—	18·4	11·4	29·8	63·2
2nd year	—	—	15·8*	25·0	19·7*	21·3	63·7	93·0	—
3rd year	—	—	49·8	13·3†	17·3*	23·0	49·5	102·9	—

* Pre-grazing cut. † Aftermath grazing.

The yield of grass, although good, was somewhat below that obtained in the very favourable season 1951. Thus the average production of dried cut grass of all ages was 47 cwt. in 1952 as against 56 cwt, in the previous year. On the other hand lucerne did very well on both fields, and on Fosters it produced the remarkable yield of 103 cwt. dry matter in the third year, considerably more than grass under any system of management.

Nitrogen responses were substantial on second and third year cut grass, averaging 6·8 cwt. dry matter per acre as a total of 4 cuts for the extra 4 cwt. of " Nitrochalk ". The permanent and reseeded grass laid up for hay in the third year also averaged 4·3 cwt. dry matter for an extra 1 cwt. of " Nitrochalk ". The nitrogen dressings on grazing land gave only small increases in dry matter per acre.

Grazing commenced on 29th May and most of the plots had 4 circuits with teams of 4–5 sheep although wider variations in stocking were necessary in special circumstances. There was a gap in the grazing for much of July and August owing to the dry weather.

The new 3-course rotation

A 3-course rotation experiment which was started in 1933 to test the long period effect of dressings of raw straw and straw compost was terminated in 1951. A full discussion of the results of three 6-year cycles of this experiment is contained in the Report for 1951, pp. 135–140. In brief, straw depressed the yield of barley and sugar beet, but increased the yield of potatoes; and its action could be explained on the assumption that straw had two main effects (1) immobilization of available nitrogen and (2) provision of readily available potash. Measurements made of residual and cumulative effects suggested that nitrogen locked up by straw or compost was very slow to return to circulation; there was no general build-up in soil fertility, due to organic manures applied over a long period.

To analyse these findings in more detail the 3-course rotation was recast for a further period commencing with the crops of 1952. The new scheme is in outline as follows:—the 3-course rotation, potatoes, barley, sugar beet, continues as before. The compost treatment is stopped, the new experiment being confined to testing straw. The plots formerly receiving only inorganic fertilizers are now maintained without any organic additions and test inorganic nitrogen applied as sulphate of ammonia in alternate years. One third of the original plots testing straw or compost continue to receive straw in alternate years, while the remainder test in the presence and absence of sulphate of ammonia, an amount of muriate of potash equivalent to the K_2O contained in the straw application. In the original experiment the straw received a quantity of nitrogen at the conventional rate, 0·7 per cent of the dry weight of straw, but in the modified scheme the straw receives nitrogen at two rates, 0·4 per cent and 1·2 per cent respectively, the straw plots having the lower rate of nitrogen being supplemented by a direct addition of sulphate of ammonia in the second year. No further nitrogen is added in the second year to straw plots receiving high nitrogen.

Every plot in the above schedule of main treatments is divided to test an addition of muriate of potash. At present the intention

is to harvest the half plots only when the crop is potatoes, as this crop is most likely to reveal differences in potash responses in the presence or absence of straw either applied directly or in the form of residues.

Irrigation experiment, Woburn

The rotation experiment testing three systems of applying water to sugar beet, barley, early potatoes and a grass mixture was continued for a second season, and the results are summarized in the report of the Physics Department. The growing period was moist enough in spring and late summer, but June and July were very dry. Irrigation at the highest level tested, approximately 5 inches, gave an increase of 4·2 tons of early potatoes, lifted on 10th July, 36 cwt. dry grass as a total of 7 cuts, 2·2 tons sugar beet roots, and 2·6 cwt. barley grain.

Short-Period and Annual Experiments

Many of the short-period and annual experiments were carried out on behalf of the scientific departments who made the necessary observations and in some cases did some of the field work. The account of these experiments will be found in the departmental reports. They were:—

Fertilizer placement experiments. (G. W. Cooke, Chemistry Department).

(1) Spring beans—Great Harpenden II, superphosphate and sulphate of potash, broadcast and placed.
(2) Broad beans—Great Harpenden II, granular PK fertilizer, broadcast and placed.
(3) Lucerne—Highfield V, superphosphate and muriate of potash, broadcast and ploughed in; with and without placed superphosphate.
(4) Red beet—Long Hoos IV, complete fertilizer, broadcast and placed.

Experiments with "nitrophosphate". (G. W. Cooke, Chemistry Department)

(1) Barley—Highfield III, "nitrophosphate" and equivalent nutrients, broadcast and combine-drilled.
(2) Old grass—Highfield IX, residues of two "nitrophosphates" applied in 1951.
(3) Potatoes—Highfield V, three "nitrophosphates" and levels of superphosphate.

Experiments on eyespot of wheat. (M. D. Glynne, G. A. Salt, Plant Pathology Department)

(1) Rotation experiment—Little Knott, 3rd year: testing 32 different crop sequences on the incidence of eyespot. These rotations are being built up for a test in wheat in 1953.
(2) Great Field I: testing two varieties; two seed rates; two levels of nitrogenous manuring applied on four occasions; and effect of spraying with sulphuric acid in early spring.

Wireworm experiment on wheat. (F. Raw, Entomology Department, C. Potter, Insecticides Department)

Geescroft; test of five soil fumigants.

Experiments on the control of bean aphis. (M. J. Way and P. Smith, Insecticides Department)

Spring beans—Great Harpenden II; six insecticides.

Control of late blight on potatoes. (J. M. Hirst, Plant Pathology Department)

Effect of copper and sulphuric acid sprays.

Virus yellows experiment on sugar beet. (J. W. Blencowe, Plant Pathology Department)

Great Harpenden II; effect of three sowing and three singling dates.

Virus spread experiments. (L. Broadbent, Plant Pathology Department)

(1) Potatoes—Long Hoos V, examination of crop grown from seed produced in an experiment carried out in 1951 testing five insecticides against aphids.

(2) Potatoes—Long Hoos V, spread of two viruses from infector plants.

(3) Cauliflower—Long Hoos VII, spread of two viruses from infector plants.

Other Annual Experiments

(1) Wheat—Little Hoos, the residual effects of various amounts of dung applied to the previous potato crop.

(2) Potatoes—West Barnfield II, 4th season, dung at 3 levels, ploughed in in winter, ploughed in in spring, and spread down the ridges. Test of sulphate of ammonia, superphosphate and muriate of potash.

(3) Potatoes—West Barnfield II, method of planting. This was a continuation and development of previous experiments started in 1949. The main comparison was between broadcast fertilizer and fertilizer placed 2 inches to the side of the seed by a planter provided with a special fertilizer placement unit. This comparison was made when planting in ridges, and also when working from the flat. Plots manured in the ridges and planted by hand in the usual way were included as controls. In two of the previous experiments this standard method had given somewhat lower plant populations and lower yields than machine-planting, and it was thought that the difference might be due in part to excessive drying out of the ridges before planting. Consequently in the present experiment one set of plots were planted by the ordinary method in ridges that had previously been exposed to the weather for a week, while another set of plots were planted in ridges that had been set up the same day. All ridges were then split back immediately. A preliminary examination of the figures shows them to be closely in line with earlier experiments carried out by G. W. Cooke for the Agricultural Research Council at outside centres. There were big responses to fertilizer. Granular compound fertilizer either placed by machine or broadcast over the ridges before splitting back was much more efficient than an equal quantity broadcast on the flat. Of the above two methods of concentrating the fertilizer close to the seed, the banded

fertilizer gave slightly better results than those obtained by the standard method. Owing to the continued showery weather during the week in early May when the ridges were exposed this treatment showed no harmful effect as compared with immediate planting and splitting back.

(4) Late nitrogen on cereals. Experiments testing top-dressings of 1½ and 3 cwt. " Nitrochalk " per acre applied when the cereals were in ear were continued for the third season in 1952. They were carried out on fields which had already received the nitrogenous top-dressings used for ordinary commercial crops, so that late nitrogen was being tested on crops adequately manured. Wheat had 2½ cwt. sulphate of ammonia on 25th April, and the late nitrogen was applied on 28th June, 44 days before cutting. Barley received 2½ cwt. sulphate of ammonia (applied 19th March for linseed which failed) and a further ¾ cwt. sulphate of ammonia combine-drilled on 13th May, and the late nitrogen was given on 16th July. This late sown barley which was not harvested till 16th September could not be regarded as a normal crop and the yields have little value. They do at least show that generous manuring cannot compensate for late sowing. Oats were an excellent crop; they had received 2½ cwt. sulphate of ammonia on 3rd March, and the late top-dressings were applied on 30th June, only 23 days before cutting.

The summer was not favourable for late nitrogenous dressings for June and July were very dry. The oats only had 0·5 inches of rain in the three weeks in which the dressings were on the land, the wheat only 0·9 inches in the six weeks' period; the barley had practically no rain for a fortnight after application, so for this crop the nitrogenous dressing could be regarded as having remained inactive till the beginnings of August. Subsequently there was plenty of moisture.

The yields of grain and straw, the increase in crude protein and the uptake of added nitrogen are set out for the three crops in the table below.

Late nitrogenous top dressings on cereals, Rothamsted, 1952

" Nitrochalk " cwt. per acre	Wheat		Barley		Oats *	
	Grain	Straw	Grain	Straw	Grain	Straw
	Yield, cwt. per acre					
0	19·0	33·7	13·1	19·6	35·5	45·5
1·5	20·9	34·1	13·5	18·3	36·4	45·5
3	20·8	35·9	13·1	19·2	35·2	45·6
	Increase in crude protein, cwt. per acre					
1·5	0·33	0·00	0·08	–0·06	0·30	0·05
3	0·32	0·06	0·02	–0·05	0·24	0·10
	Percentage uptake of added nitrogen					
1·5	23	1	6	–4	21	3
3	11	2	1	–2	8	3

* corrected to 85 per cent. dry matter.

Wheat was only a fair crop owing to a rather severe attack of eyespot; there was a small increase in yield for the smaller dressing of " Nitrochalk ", and the gain of 0·33 cwt. crude protein per acre in

the total produce was intermediate between the good result obtained in 1950 and the poor one in 1951. Barley, which so far has been the most responsive crop gave practically no response to late nitrogen in 1952, but for reasons already stated the crop was very poor. The yield of oats was excellent and was not improved by late nitrogen which in this case only had three weeks to act. There was a gain of 0·3 cwt. protein, chiefly in the grain, for the light dressing of " Nitrochalk ".

The experiments on wheat and barley were enlarged to test a small pusher combine specially designed by the National Institute of Agricultural Engineering for harvesting small plots, the standard for comparison being the normal binder procedure used at Rothamsted. These and other similar harvesting tests are discussed in the farm report. In the present report figures derived from harvesting by the standard procedure have been used.

Soil conditioners

A number of small-scale experiments were laid out in April 1952 at Rothamsted and Woburn to test the effect on soil structure and crop yields of a synthetic soil conditioner—the sodium salt of a hydrolized polyacrylonitrile, supplied as " Krilium CRD-189 ". In one set of experiments, two on each farm, the conditioner was incorporated at two rates (3 and 6 cwt. per acre) by rotary cultivation and also tested at the lower rate by broadcasting and raking in. The experiments were in 4 × 4 Latin squares with plots of 5 × 2 square yards. Four rows of each of four crops—carrots, red beet, clover and ryegrass—were taken in strips across every plot of the experiment. Several small-scale experiments were made on other crops—sugar beet, potatoes, wheat, barley. Where the conditioner was raked into the soil surface, the Rothamsted experiments sometimes showed a honeycomb of small pits which were empty in dry weather and full of wet jelly after rains. The soil adjoining the pits had a hard and somewhat darker crust. Similar observations were occasionally made where the conditioner had been incorporated by two rotary cultivations, but in most of the experiments it was difficult to detect any consistent visual differences in the structure of surface soils with contrasted treatments. There was no evidence of any appreciable increase in crop yield from using the conditioner. In these experiments the active ingredient was applied directly without a filler. Its hygroscopic properties may have prevented the conditioner from being intimately incorporated with the soil. Although the results of these preliminary experiments are not very promising, it is possible that improved methods of preparation and incorporation may be found in the future.

Staff

Mr. G. V. Dyke transferred from the Statistical Department to fill a vacancy in the Field Experiments Section caused by the death of Mr. J. W. Weil.

THE FARMS

J. R. Moffatt

Rothamsted

The year 1951-52 proved generally satisfactory, in spite of rather extreme fluctuations of weather conditions. Land work in autumn 1951, after a brief good start, was completely stopped by very heavy rainfall for over a month, and drilling of winter cereals was considerably delayed. A short fine spell early in December enabled some more wheat to be drilled, but the acreage sown was lower than had been planned.

The winter of 1951-52 was a mild one except for freak snows towards the end of March; January and February were reasonably dry, and good progress was made with winter ploughing. A very welcome burst of spring weather starting in the last week of February facilitated the preparation of good seedbeds much earlier than usual, and the drilling of spring cereal was completed by the middle of March.

The preparation of seed-beds for root crops followed, but the planting of these crops was delayed by the freak snows already mentioned. However the root crops were all planted under reasonably good conditions by mid-May. May saw the beginning of a long drought which lasted until the end of July. The hay crop did not suffer much as it was cut early before the drought became too severe. Although June and July were very dry the corn crops continued to grow well, though they ripened much earlier than usual. Mangolds and sugar beet made only very slow growth, but the drought was felt most by the potato crop which made very little growth.

The drought broke in early August, which month gave twice the normal rainfall. The corn harvest was seriously interfered with but the root crops took a fresh lease of life. Potato lifting started under ideal conditions about the middle of October, but before the operation was completed the weather broke and for the second successive year November was very wet. Towards the end of the month there was a spell of severe wintry weather, with a considerable fall of snow, which lasted well into December. The harvesting of the mangolds and sugar beet was delayed; the mangolds suffered considerable damage from frost, and the sugar beet crop was not disposed of until well into January 1953.

Field Experiments

The number of experimental plots at Rothamsted totalled 2,419, an increase of over 500 above the 1951 figure. About 200 of these were drilled and harvested by departments of the Station, and not all the experiments needed carrying through to harvest. There was, however, a big increase in the amount of experimental work, which in itself is rapidly becoming more complicated each year. With such a very large programme of experimental work the planning of the operations is a formidable task, and any delay caused by the weather or breakdown of machinery is likely to upset

the orderly execution of the work. The programme of field experiments is now so full, and the work is so spread over the year, that it is most unlikely that any leeway caused by a delay can be made up subsequently. It is therefore difficult to see that there can be any great expansion of field work which can be guaranteed close supervision and proper execution, without considerable risk that some of the work will suffer.

Extra managerial and supervisory staff are being engaged, and more of the experimental work is being mechanized each year in order to keep pace with the ever-increasing amount of experimental field-work.

Cropping

The farm consists of about 475 acres, of which 368 acres were under arable crops. There is still about 75 acres of old grassland which is either under experiments, or reserved for future experiments, or unploughable. On the tillage acreage sixteen different crops were grown, the main ones being wheat 69 acres, barley 87 acres, oats 16 acres, potatoes 40 acres, kale, mangolds and sugar beet 18 acres, with 11 acres of experimental land under fallow.

Crops, Varieties and Growth

Wheat

Squareheads Master 13/4, Yeoman and some Bersée were grown on experimental areas, but Nord Desprez was the only variety grown on non-experimental fields. Although several fields were sown late, the mild winter resulted in rapid germination and good growth. Heavy nitrogenous top dressings were used and most of the crop was sprayed against weeds. Despite the drought good growth was maintained through the season, and the crop ripened earlier than usual. Yields from the areas threshed are very satisfactory.

The Nord Desprez was severely attacked by Yellow Rust which must have reduced the yield. A varietal trial on land where lodging was foreseen indicated that Hybrid 46 and Cappelle had stiffer straw than the Nord Desprez, and were not susceptible to the strain of Yellow Rust present in 1952. Cappelle will, therefore, replace Nord Desprez as the main wheat for non-experimental fields. The drilling of Broadbalk, the Classical wheat field, was delayed until early December, but the crop made good growth subsequently, and at harvest looked better and cleaner than it has for many years. Practically no lodging occurred and yields on most plots were above average. Wild oats, the presence of which threatened the extinction of the experiment a few years ago, have been very greatly reduced in number by hand-pulling each year, and the weed was hand-pulled again in 1952.

Barley

Plumage Archer was grown on all experimental areas and on a few areas of non-experimental barley, but Herta replaced Plumage Archer on most of the non-experimental land. The Herta, a stiff-strawed, heavy-yielding variety, was liberally top-dressed with nitrogen and grew extremely well throughout the year. Yields

averaged over 32 cwt. per acre and it was all sold for seed purposes. No lodging occurred with the Herta but some of the Plumage Archer was lodged by the heavy rain just before harvest. One late-sown area of Plumage Archer which followed a crop of linseed destroyed by flea-beetles, suffered severely from the drought and a heavy attack of mildew. This area ripened very late and unevenly, and the yield was low.

Hoosfield, the Classical barley field, was so very badly infested with wild oats that most of each plot was cut green before the wild oats ripened, a small area of each plot being left for harvest. It was hoped to hand-pull the wild oats from the harvested area, but the oats were so numerous and the dry weather so accelerated their ripening, that this was not accomplished.

Oats

Sun II has been the variety used in the past, but in 1952 Blenda, another cross of the same parentage, was tried out, together with White Opus. In the early part of the season the Blenda was thinner and more backward than the Opus, but it subsequently filled out and yielded 36 cwt. per acre. The Opus grew well and looked a thick even crop, but it has not yet been threshed. Yields from a varietal trial indicated that there was little to choose this season between Sun II and White Opus, which were slightly better than Blenda. Marne gave slightly the highest yield; the mean of the four varieties was 36 cwt. per acre.

Linseed

About 11 acres of Valuta linseed were sown with seed saved from the 1951 crop. The germination was known to be low and though allowance was made in the seed rate the ensuing plant was thin. An attack by flea beetles followed which decimated the plant, so the area was worked for another crop. A small area in another field was carried through to harvest, but here again the plant was very thin and the crop was weedy. As the crop is not an economic one it is unlikely to be grown again unless to meet special circumstances or conditions.

Potatoes

As in previous years, Majestic potatoes only were grown, as this is the standard variety for all experimental field work. The non-experimental areas were planted with the same variety. Stock Seed was used on all experimental areas and Class ' A ' seed was purchased for non-experimental areas. The seed was obtained from Northern Ireland.

The seed went further than was anticipated so the acreage was increased to use all of it. This brought the acreage to the biggest for many years. As planting was mostly done by dropper attached to the tool bar of a ridging plough, and subsequent clearing operations were mostly mechanized, the increased acreage was easily handled until it came to lifting. A mechanical weeder was used to keep the crop clean. Schoolchildren picked the crop from the plots, which were harvested first, and gave some help with the non-experimental crop. They were recalled to school before lifting was completed,

and though a supply of gang labour was subsequently found in Bedford, the weather broke before this could be organized. There were still about 2 acres of potatoes in the ground at the end of the year. In view of the considerable difficulty in getting pickers in this area, where casual labour is non-existent, the area of the crop will be reduced considerably in future. The possibility of mechanical harvesting has been investigated, but the heavy, stony soil at Rothamsted mitigates against it. There is certainly no machine capable of handling small experimental plots.

The crop was seriously retarded by the summer drought but when the rain came in August, vigorous growth took place. This resulted in many of the tubers becoming mis-shapen and brought on an attack of Late Blight. Two copper sprayings at medium volume were given and the haulm remained green until well into October. It was burnt off early in October and the lifting started about the middle of the month. The crop was stored in large heaps in the barns and will be sorted throughout the winter.

A large-scale trial was carried out to test whether Late Blight could be controlled by spraying with copper compounds at volume as low as 10 gallons per acre. Results indicated that in a season such as 1952 when the epidemic was not severe, the protection afforded to the leaves by some materials when applied at 10 gallons per acre could be as good as at 40 gallons.

Sugar beet, fodder beet and mangolds

The area of each of these crops was limited to the experimental areas, as the labour demands at singling time clash with the requirements of other work, and no seasonal labour is available. The crop also prevents difficulties on our heavy soil at lifting. The hard weather in late November and early December did considerable damage to the mangolds and much of the crop will have to be used earlier than usual to prevent losses by rotting. The leaves of the sugar beet were likewise damaged, and the weighing of the tops was abandoned; the roots were not damaged though lifting was delayed until early January 1953. A variety trial with four varieties of fodder beet of different types was carried out, but yields were almost identical at 26 tons per acre.

Kale

Both Marrow-stem and Thousand-head kale were grown for use during the winter. The Marrow-stem is cut and fed to cattle in yards while the Thousand-head is folded by sheep. The area was reduced this year to keep pace with the reduction in sheep numbers.

Flea beetles were active throughout the summer and one small early sown area was destroyed. This was redrilled and the beetles on this and on the other area of kale were controlled by two medium volume sprayings using a 15 per cent emulsion of D.D.T.

Grassland

The grassland was very productive in the early part of the year. The hay crop was cut and baled during June under good weather conditions and a heavy crop of good quality hay was secured. A

top-dressing of " Nitrochalk " was given to all fields after the removal of the hay crop but the dry weather prevented this from having any immediate effect. During the latter half of June grass became very scarce and during July many of the fields were badly scorched. They rapidly improved with rain during August and fair growth was maintained until the end of the growing season.

Most of the grass on fields were sprayed with M.C.P.A. weedkiller which had a marked influence on buttercups and thistles.

Cereal Harvest

Owing to the drought all cereal crops ripened much earlier than usual. Cutting starting on 22nd July and continued without a break for ten days and excellent progress was made. Carting and combining of barley started before the end of the month. However, a spell of very wet weather then occurred and for a fortnight only intermittent work could be done, but a fine spell in the last week of August enabled the harvest to be completed before the end of the month.

All the wheat and oats were cut by binder and stacked under the Dutch barns at the farmstead. All the non-experimental barley was combined and the straw baled. The barley was all stored either in bags or in small plywood grain bins until the end of the year when it was sold without further cleaning. The platform drier was not used as much as in 1951 as none of the early-combined corn needed any drying; only about 22 tons needed drying this year.

During the harvest, trials were carried out to compare a standard Massey-Harris 726 combine, and the experimental combine of the National Institute of Agricultural Engineering with the present method, using a binder for harvesting experimental cereal plots. A preliminary examination of the results indicates that both combine-harvesters have great possibilities for the work, and effect a very great saving in time.

Livestock

Cattle

During the year 26 Irish black polls and 17 Hereford-cross store cattle were purchased for fattening, bringing the number of feeding cattle to 88. It was hoped to fatten about 50 of these from the grass during the year, but grass keep became so scarce during July and August that only 37 were sold by the end of the year. The remainder will be overwintered, some in covered years, and some outside. Feeding will consist of hay, oat and barley straw, and kale, with a small supplement of home-grown grains.

Sufficient farmyard manure will be made for the experimental plots and for the non-experimental area of potatoes.

Sheep

The rather mixed home-bred flock of 152 ewes produced 220 lambs at tailing time, a percentage of 145. Some were sold fat or at store sales in the autumn, but sufficient were retained for stocking the grazing plots at Rothamsted and Woburn in 1953. In the autumn many of the older ewes were drafted from the flock which was reduced to 80. These will probably be replaced in 1953 by a

small number of Scotch Half-bred ewes which will be kept solely to rear sheep for the grazing experiments.

Machinery

The purchase of new equipment was confined mainly to replacing worn-out equipment, and by duplicating some items to enable full use to be made of fine spells of weather in busy seasons. A semi-mounted side-delivery rake and a bale sledge were purchased and these considerably expedited the handling of both hay and straw in conjunction with the pick-up baler. The baler was tried out for harvesting crops of hay from experimental plots which, in the past, were weighed loose in the field or carted to the weighbridge. The scheme worked very satisfactorily and will be extended wherever possible. Two dung spreaders were purchased for use with a dung loader, which worked very efficiently in the cattle yards.

Buildings

No major building work was undertaken but some modifications and adaptations were made. The farm cottages were modernized, all now being fitted with modern sanitary conveniences, including baths.

Plans are in hand for the bulk handling of grain; in outline they consist of the erection of 4 bins with a framework of timber and with plywood sides, each bin to hold about 18 tons of grain. It is planned to fill these by using a pneumatic conveyor; and to empty them by fitting a suction attachment to the conveyor and bagging off direct.

Estate Work

A considerable amount of general estate duties were carried out during the year. This included hedging, fencing, and the felling of dead trees for use as timber. The gradual replacement of old fences by concrete post and wire fence was considerably accelerated during the year.

Woburn

The work of Woburn Farm was directed and managed by the staff of the Rothamsted Farm.

The experimental work at Woburn could not be extended owing to the shortage of permanent farm staff, and the non-experimental cropping schedule had to be altered for the same reason. Conditions at Woburn are ideal for the sugar beet but the large labour demands made by this crop necessitated its exclusion, except for small experimental areas. A considerable acreage of potatoes was grown as the casual labour needed for lifting the crop can be obtained from the neighbouring town of Bedford. Plans are now passed for the erection of a pair of farm workers' cottages and building should commence almost immediately. This should overcome the difficulties of permanent staff.

The mechanization of the field operations both on experimental and non-experimental areas is almost completed, though one horse is kept for odd work and light operations on experimental plots. Most of the operations at the farmstead are also mechanized, electricity being used as the source of power where possible. For major operations such as threshing and baling hay and straw, the

Woburn Farm is still dependent on the Rothamsted Farm for machinery and labour, but in all other operations the Woburn Farm is now self-sufficient.

The last of the badly overgrown hedges and neglected ditches received attention during the year, and a big all-round improvement to the farm has resulted. It is now hoped to maintain these in suitable condition. Several of the old dilapidated fences were removed and new fence lines have been fixed which will facilitate the working of the fields.

The main obstacle to efficient farming and reliable experimental work is damage caused by game and other pests. Despite the precautions taken and the use of scarers, severe damage has been done to all crops by rooks, and pigeons, and we are working in close collaboration with the Pest Department of the Bedfordshire Agricultural Executive Committee to effect a reduction of the damage. The perennial problem of damage by pheasants seems almost impossible to resolve, but it is hoped that as a result of representations made to the owner of the estate some diminution of the damage can confidently be expected in future.

Of the 127 acres farmed in 1952, 64 acres were devoted to cereals, 20 acres to potatoes and 28 acres were under grass. The remaining area was under various experimental crops except for a small area under fallow.

For the second successive year, weather conditions in the autumn (1951) were bad and severely affected the farm work. The lifting of potatoes was delayed and the sowing of the winter corn for the 1952 crop was also delayed. The very heavy rainfall in November 1951 made land work impossible but an improvement in December enabled a little more wheat to be sown; unfortunately this late sowing was destroyed by birds and had to be redrilled in spring with Atle wheat. The variety of winter wheat mainly grown was Nord Desprez. Owing to the damp and mild conditions during January and early February, little progress was made with the ploughing of the heavier fields, and this was only completed towards the end of February with the help of equipment from Rothamsted.

Good spring seedbeds were secured during the latter half of February and March, and sowings started early in March. Plumage Archer barley was sown on all experimental areas but was replaced by Herta on much of the non-experimental areas as this is a heavier-yielding variety with a very stiff straw. The barleys all grew fairly well but looked rather patchy and some of the yields were disappointing. Soil analysis showed that some of the fields were rather acid, and a programme of chalking these non-experimental areas was commenced soon after harvest. Most of the barley was satisfactorily disposed of as seed.

The Permanent Barley area in Stackyard field, where nothing but barley has been grown since 1877, has been consistently unable to grow a satisfactory crop of spring barley for many years. The area is severely infested with Spurrey (*Spergula arvensis*) and though the area has been fallowed from time to time, the weed did not seem to germinate well except in the presence of the barley, and herbicides had very little effect upon it. In an attempt to reduce the effect of the severe weed competition in spring, part of each plot was

sown with Pioneer winter barley late in the autumn of 1951, the remainder of each plot being sown in the following spring with Plumage Archer. The winter barley made good growth throughout the season and developed into a nice even crop at harvest time, and there appeared to be less Spurrey than in the spring-sown crop. The spring-sown crop produced its usual poor uneven crop. In view of the practical importance of this result, if it is substantiated another year, the parts of the plots under the two varieties have been reversed for the 1953 crop.

All the non-experimental corn crops received fairly heavy top-dressings of nitrogen in the spring, and all were sprayed with hormone type weedkillers.

The various crops in all the experiments were sown in good time and under excellent conditions during March and April, and made a good start. The non-experimental potatoes were planted by a dropper on a three-row ridger and this work was finished by early May.

Good growth of all crops and grass was maintained throughout May and June, but by July the root crops were showing signs of drought. July was very hot and dry, and the root crops made very little growth, though it was very noticeable that on areas where dung had been applied that the potato haulm was more green and vigorous; the cereal crops began to ripen much earlier than usual.

Grassland was productive throughout the season and an excellent crop of hay was taken early in June. It was baled in the field with a pick-up baler, the bales being left to mature for several days before being carted. A good aftermath was secured by a top-dressing of " Nitrochalk ", and this was grazed off by bullocks.

The planting out of the experimental crop of winter cabbage was done in late June and early July, and all plants had to be watered in twice, but even this could not prevent a very slow recovery of the plants and many replacements were needed. The planting of the winter cabbage after early potatoes on the Irrigation Experiment was delayed owing to the dry state of the soil, and eventually the land had to be irrigated to the equivalent of $\frac{3}{4}$ in. rain before planting could start. Severe attacks of mealy aphis developed later in the month and all cabbage crops had to be sprayed with Parathion. These crops therefore had a very bad start and they were later severely damaged by pheasants and pigeons. Hearting up was considerably retarded and it is possible that a high proportion will have to be disposed of as " greens ".

In the market garden experiment in Lansome field the drought considerably retarded the growth of the spring cabbage and the crop was not cleared until the end of June. Owing to the dry state of the soil the transplanting of the following leek crop had to be delayed until August. The crop then made reasonable growth until the hard weather set in towards the end of November ; there has been practically no growth since. The red beet in another block of this experiment grew reasonably well. The crop was marketed periodically throughout the summer, the last pulling being done towards the end of September. This crop was followed by spring cabbage but pigeons practically destroyed the plants despite the fact that explosive scarers were in use at the time.

The cereal harvest started much earlier than usual. Cutting commenced on 25th July and some was carted before the end of the month. Despite some interruptions from the weather in August the harvest was completed before the end of the month. The yield of the crops was generally rather below expectations.

The fairly heavy rain during August and September enabled the root crops to restart growth, but this sudden change in growing conditions caused many of the tubers to become mis-shapen. Some Late Blight (*Phytopthora infestans*) also occurred and medium volume spraying with a copper compound was carried out on two occasions to reduce the attack. The haulm was burnt off with sulphuric acid during late September and October. The experimental crops were lifted early in October but the non-experimental crops were left until the autumn-sown cereals were drilled on the experimental areas. Yields were quite satisfactory and the tubers were reasonably free from blight, though quite a few were either mis-shapen or affected with scab. The crop is being disposed of rather earlier than usual.

About 25 acres of winter wheat were drilled during November, despite the wet conditions. The early onset of severe wintry conditions in late November and December made germination slow. This and the absence of natural food for birds resulted in severe damage to the wheat by pheasants, rooks and pigeons and it is probable that the whole area will need resowing in spring. Winter land work was well forward by the end of the year.

The small Large White herd of pigs was maintained and the progeny was carried on to bacon weight. They were fed largely on home-produced grain and unsaleable potatoes, with a protein supplement of earthnut meal. Food for the sows consisted mainly of a purchased high-protein ration, as nuts for the dry sows and as meal for suckling sows.

Most of the difficulties under which the Woburn Farm was labouring when its direction was handed to the staff of the Rothamsted Farm in 1947, have now been surmounted. It only remains to reduce or eliminate damage caused by pests for the Woburn Farm to become an efficient farm on which reliable field experiments can be carried out.

WOBURN EXPERIMENTAL STATION

H. H. Mann

Season

The year 1952 is the third in succession at Woburn that has had a more than average fall of rain. The spring, till the middle of May, was wet, though the high rainfall did not interfere with agricultural operations as much as in 1951. From the middle of May, there was a period with little or no effective rainfall, and this lasted till the end of July, when grass almost completely dried up, crops wilted which had not got a good start in the spring, and a chance was given for irrigation to show its effect in combating drought conditions. At the beginning of August a complete change came over the scene and each month thereafter had more than an average rainfall, accompanied by low temperatures which interfered with the ripening and harvesting of some of the more delicate crops whose possibilities we are attempting to find out at Woburn. The meteorological records from October 1951 to the end of 1952 are shown below.

Meteorological records for 1951-52

Month	Rainfall			Temperature			
	Total fall	No. of rainy days	Bright sunshine	Max.	Min.	1 ft. in ground	Grass Min.
1951	ins.		hours	F.	F.	F.	F.
October	1·24	11	100·8	55·8	39·2	49·0	34·8
November	4·35	26	62·9	51·8	41·9	45·9	37·1
December	1·56	16	60·8	47·0	35·7	41·0	31·4
1952							
January	1·51	14	86·8	41·9	32·1	37·1	28·7
February	0·67	8	87·4	42·8	30·9	36·3	26·9
March	3·56	22	90·5	49·4	37·5	43·3	34·6
April	1·93	15	161·8	58·7	40·3	48·0	35·8
May	2·46	15	216·5	65·3	46·5	57·9	42·7
June	1·19	11	207·2	67·7	48·8	60·7	44·6
July	0·39	6	221·5	72·2	52·9	66·7	49·1
August	3·18	14	183·2	69·5	52·9	62·9	48·9
September	3·06	17	119·1	59·3	44·1	54·0	38·7
October	2·96	18	98·7	53·5	41·0	46·8	36·9
November	3·24	16	65·4	43·7	32·7	39·9	30·0
December	2·06	19	68·3	41·8	30·0	35·8	27·7
Total or mean for 1952	26·21	175	1606·4	55·5	40·8	49·1	37·1

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them which may be recorded here.

In the last report it was stated that in the Permanent Barley plots, where there has been, with various manuring, no other crop than barley since 1877, the land had become so foul with wild oats that these could only be got rid of after three years of fallowing, and

after these had been eliminated, the ground was still so badly affected with spurrey (*Spergula arvensis*) that it was impossible in 1951 to ripen a crop of spring barley and the whole had to be ploughed under while the barley was in the green stage. In view of the fact that, in any case, the yield of spring barley had been steadily going down on these plots in spite of heavy nitrogenous manuring, it was decided to see how a crop of winter barley would fare on each plot as against the usual crop of spring barley. The result was remarkable, for the winter barley flourished on the same plots that produced a small, miserable crop of the spring variety, and gave a better yield than we have had for many years. The actual yields of corn, on the average, for each set of plots with three variations of nitrogenous manuring, were as follows:—

	Winter barley (" Pioneer ")	*Spring barley* (" Plumage Archer ")
2 cwt. " Nitrochalk "	25·2 cwt. per acre	10·8 cwt. per acre
4 cwt. " Nitrochalk "	28·5 cwt. per acre	10·3 cwt. per acre
6 cwt. " Nitrochalk "	25·8 cwt. per acre	8·6 cwt. per acre

It will be seen that the yield of winter barley was exceptionally high while that of spring barley on the same plots with the same manuring practically amounted to a crop failure. The cause of this is quite unknown at present. By some it is put down to the relative absence of weeds in the winter barley : by others it is connected with the deeper-rooted system of the winter barley which taps a layer of soil which had not been reached by the long continued growth of spring barley. The experiment will be repeated in 1953, placing the winter barley where the spring barley was in 1952 and *vice versa*.

New Crops

In previous reports I have noted the successful growing of some of the early varieties of hybrid maize, obtained from the United States, with an annual yield of well over 30 cwt. of dry grain per acre in three successive years. This year two such hybrids have been compared with a large selection of maize types developed in Europe. Up to the end of July conditions were eminently favourable for a semi-tropical crop like maize, except that at the end of the period it appeared affected to a small extent by the continued drought. After the beginning of August, conditions were not so good. It was damp and cold, and, while the maize continued to grow, the ripening was slow and the tips of the ears tended not to fill. This applied to all the varieties grown, whether the hybrids had been developed in America or Europe. The yields were in all cases, nevertheless, quite high and in one case over 50 cwt. of dry grain per acre were reaped. This was with Wisconsin 275, which gave 92 per cent ripe ears, after being sown on 1st May and reaped finally on 10th October. This was nearly approached by Wisconsin 240, which planted on the same date as the above gave a yield of over 38 cwt. per acre. All varieties were manured with 3 cwt. " Nitrochalk " per acre.

Two things have been made clear by this year's work. The first is that while too early sowing is not advisable, for maize germinates poorly if the temperature in the soil is lower than 50°F, yet delay

beyond this point is disastrous. The difference between the crop sown on 1st and 16th May was 6 cwt. per acre with Wisconsin 240 and 12 cwt. per acre with Wisconsin 275, and in the last case, the later sown seed only ripened 80 per cent of the grain. It is evident that the choice of the date of sowing is very vital in the growing of hybrid maize in Britain. The second matter is connected with the wet weather usual at the time of ripening of maize in this country. This means that it will be necessary to make provision for the drying of the maize ears much more elaborate than those which are usual in most maize growing countries.

Fodder Crops for Semi-acid Soils

For some years we have been trying to find suitable fodder crops for our semi-acid soils, which could be planted, say in May, and which would give a large amount of green forage about the end of August, when the ordinary grass pasture is beginning to show signs of slowing down in growth. Several of these have given good results in 1952. Perhaps the most notable of these is the sweet lupin, which grows well in acid soil and of which some very productive types now exist. The most notable of these is "Weiko" a yellow-flowered kind, which has now for several years given us very large yield of green stuff in August or September, which, though not very readily taken by farm animals, forms a good feedingstuff. For the last two years, the actual weight of green fodder obtained on or about 20th August from seed sown early in May, was as follows :—

Year	Weight of green stuff per acre tons	Dry matter in green per cent.	Hay equivalent per acre tons
1951	14·1	12·6	2·09
1952	15·7	12·1	2·24

The two seasons were both wet ones, except for the months of June and July in 1952, and the lupin grew vigorously and well. By 20th August it had podded well but the pods remained green. After this date the pods rapidly ripened, and a new green growth appeared on the plants. The seed obtained on the area left for the purpose was abundant and it was taken in a rather wet condition in the latter half of October, but was immediately dried, as lupin seed cannot be stored unless in a very dry condition. The utility of sweet lupins as a fodder crop under the conditions specified seems now proved and it only needs an available supply of seed to make it a valuable additional asset to stock farmers on suitable land.

Two other leguminous fodder crops have been again tested in 1952. These are serradella and birdsfoot trefoil. We have now grown the former of these for three years, when we have obtained yields as follows :—

Year	Weight of green stuff per acre tons	Dry matter in green per cent.	Hay equivalent per acre tons
1950	11·6	15·7	2·14
1951	6·8	16·6	1·33
1952	16·3	14·8	2·84

The fodder, when cut on 20th August, was greedily taken by all forms of livestock, and it is evident that we have a new crop in England which may have considerable possibilities for the future.

At present the seed is difficult to get, and in a wet season like 1952 I was not able to save more than a very small amount, whereas in the dry season of 1950 the seed yield was considerable.

As regards birdsfoot trefoil, which is supposed to be a fodder crop which will flourish on land which is too poor to give a normal growth of clover, and which has the advantage of being a perennial and so can be kept for at least two years, one difficulty we have found is the slowness with which the growth starts. When sown at the beginning of May, it has in the last two years shown little growth till after the end of July, but later in the season it flourished exceedingly, and at the end of September gave a large yield of good fodder. The narrow leafed variety, in fact, gave 12·5 tons of green fodder per acre, equivalent to 2·8 tons of hay per acre. The area has been left for a second season, and it will be remembered that, on a previous occasion, birdsfoot trefoil gave 19·4 tons of green fodder at the end of July in the second year.

Irrigation Experiments

The general results of the irrigation field experiments which have been carried on at Woburn during the last two seasons will be described by Dr. Penman, who is in general charge of them, but there are at least two points which we have noticed and which seem worthy of record in this report.

First with regard to the grass crop and the effect of irrigation on the proportion of clover and grass in the product from the various plots, both with low and high nitrogenous fertilization. In all cases and at every level of irrigation, the proportion of clover in cuttings made throughout the season, is (as would be expected) far smaller when the nitrogenous manure added is large than when it is small. The plots with the larger amounts of irrigation water have always given a bigger proportion of clover than where no irrigation was used. The figures obtained in a botanical analysis of the cut grass with no watering and with the largest amount of water given are as follows :—

	Grass crop cut on dates given— Percentage of clover in produce			
	14th June	*11th August*	*9th September*	*3rd October*
	per cent.	per cent.	per cent.	per cent.
No watering	4·6	4·8	22·4	11·6
Maximum watering	13·7	30·5	32·3	25·3

This agrees with what was found with these plots in the first year after sowing, and would suggest that irrigation not only increases the yield of a grass ley but also tends to increase the proportion of clover and hence the feeding value of the grass cut from it.

With regard to the barley section of the experiment a test was made as to the effect of irrigation on the percentage of nitrogen contained in the grain. Even if the yield was little affected by the irrigation it would be of importance to know whether the nitrogen content was altered to any considerable extent by the use of irrigation water. As a result of analyses of the grain in two successive years, it seems, however, clear that there is little difference as the following figures show.

	Nitrogen in barley grain		
	1951	1952	Mean of two years
	per cent.	per cent.	per cent.
No watering	1·52	1·37	1·45
Maximum watering	1·44	1·46	1·45

Clover Sickness

The year has been employed in clearing up some doubtful points in connection with the study of clover sickness which has occupied us at Woburn for so many years, and with a final effort in 1953 we hope to be able to propound with some certainty a general explanation of the phenomenon. The provisional conclusions stated in last year's report seem to be substantially confirmed. We have still not been able to isolate the toxic material in the soil which causes the clover failure, as it appears to be practically insoluble in water and also in alcohol, and such isolation must remain a problem for the future. But in the meantime, it seems clear that it is sensitive to heat, that its influence can be reduced by the addition of certain forms of colloid material, and that it gradually, though only gradually, disappears if clover or a similar crop is not grown on the soil.

Laboratory Work

Both work in the plot culture station and in the laboratory at Woburn has been restricted in 1952 by the demands of the irrigation experiments for attention, and has hence been almost entirely concerned with what was necessary in connection with the field experiments. Most of this falls on Mr. Barnes and his staff, and they have been fully employed in these directions during the past year.

SOIL WORK IN THE COLONIAL TERRITORIES

H. GREENE

On Singapore island plans are being made to increase local production of fresh vegetables : probably a more important objective is to increase rice production in the Federation of Malaya to provide more human food and larger supplies of bran and broken rice that can be fed to pigs forming the prime mover in the ingenious system operated by the Chinese market gardener. In the Federation of Malaya, the Department of Irrigation and Drainage and the Department of Agriculture have been achieving outstanding results in spite of very severe physical difficulties and grave personal danger. Nevertheless there is perhaps a gap which should be filled as soon as terrorism is sufficiently controlled to permit expansion of agricultural research. Average rice yields in Malaya are low and detailed experimental work under adequate conditions is needed to improve them. In particular it seems necessary to establish one or more areas, totalling perhaps 2,000 acres, having greatly improved control of water. Possibly pumps mounted on barges may help to meet the need for research on rice growing, a need which has been explicitly recognized by past and present Directors of the Departments concerned.

Brief examination of some coastal soils in Malaita and Guadalcanal make it possible to confirm the recommendation of Mr. D. H. Urquhart that cocoa is a promising crop for peasant farmers in the British Solomon Islands Protectorate. Like the Argonauts of the Western Pacific described in 1922 by B. Malinowski, the Solomon Islanders are not only skilled but are artistic gardeners and it is probably a good plan to recognize their talents in this direction. Public health is an urgent problem for the Islanders suffer from malaria, hookworm, leprosy and yaws.

The Directors of Agriculture in Sarawak and North Borneo have proposed setting up in Labuan a joint laboratory for study of soil and entomological problems. This plan is likely to receive support from Colonial Development and Welfare Funds. Rice production is being increased in Sarawak by use of small pumps and in North Borneo by extension from existing rice growing areas. These sound and modest projects may well lead to more rapid expansion later. In North Borneo Mr. J. L. Greig considers that major economic interest attaches to the production of Manila hemp which is grown near Tawau in soil derived from volcanic mud flow. Professor C. W. Wardlaw was impressed by the good recovery made by the hemp under the management of Borneo Abaca Ltd., a subsidiary of the Colonial Development Corporation. Competition from weeds and occasional dry periods had injured the crop: a suspected virus disease seems of less importance. Soils suited for hemp are to be surveyed by Mr. T. R. Paton, a Colonial Research Student, who received post-graduate training in this country under Dr. A. Muir

and who is receiving further training in soil survey in New Zealand under Mr. N. H. Taylor.

Another Colonial Research Student, Mr. I. T. Twyford, who received post-graduate training at the Macaulay Institute, has joined the Department of Agriculture in Fiji in time to take part in laboratory studies associated with the soil reconnaissance of Fiji which has been started by the generous and valued help of the soil surveyors of New Zealand. Very satisfactory reports are received from Mr. A. C. Venn, a Colonial Research Student who received post-graduate training in field experimentation under Dr. E. M. Crowther and Dr. G. W. Cooke. Mr. Venn is now in Basutoland and has made a good start in applying these techniques there. Mr. R. F. Montgomery and Mr. A. J. Smyth, who formerly held Colonial Research Studentships, are now working under Dr. H. Vine in the Cocoa Soil Survey in Nigeria of which good reports have been received. Mr. E. M. Clegg has taken up his duties as Soil Surveyor in Northern Rhodesia. Another Colonial Research Student, Mr. T. E. Tomlinson, after completing two years post-graduate research in Oxford has spent some time under Professor L. Wiklander in Sweden and is now working under Dr. R. K. Schofield in preparation for his duties at the Rice Research Station at Rokupr in Sierra Leone. The estuarine and alluvial soils of West Africa can be reclaimed for rice but contain sulphur, part of which is readily oxidized to sulphuric acid in amounts that can prevent plant growth. There are vast areas of such soils that may be reclaimed for rice production but we have yet to learn how best to master the intricate technical problems involved in reclamation.

It is possible that weathering by sulphuric acid is of wider occurrence than has hitherto been suspected. In April 1952 Dr. Elizabeth Alexander, a geologist then resident in Singapore, showed Dr. Greene deep exposures of sedimentary material ranging from stones and gravel to sand and clay. The sediments had been raised to a nearly vertical position by emergence of a granite mass now forming the central part of Singapore island and of the Malayan peninsula. The sandy, yellow parts of the sediments showed Liesegang surfaces in close conformation, predominantly horizontal but having a wavy outline. The upper part of the exposure had red and white mottling such as is commonly found in the humid tropics in the deep subsoil at the foot of higher land (perhaps in this case at the foot of a higher mass of granite). The red and white mottling was evidently a later process than the Liesegang formation which, it is suspected, resulted from the progressive oxidation of sulphur by percolating water. A newly-formed gully in similar geological material a few miles from this site had exposed at depth a grey sandy sediment which when tested with indicator proved to be of high acidity such as occurs when sulphur or sulphide is oxidized to form sulphuric acid. It seems possible that mangroves or other plants accumulated sulphur during deposition of the sediments so that when the sediments were tilted they constituted nearly vertical sheets of porous material impregnated with organic residues ready to produce strong acid as soon as they were reached by drainage waters containing dissolved oxygen. Year after year a progressive

downward percolation of oxygen contained in drainage water might well produce the Liesegang surfaces. Near the most recent and deepest surface there would be a layer of acid water capable of decomposing clay and of becoming charged with iron and aluminium in solution and containing silica in a finely divided state. As this liquid drained downhill through media differing in porosity, diffusion and hydrolysis would make it possible for the sesquioxides to separate out in nearly pure forms as apparently they have done.

These exposures in Singapore have been examined by Messrs. C. G. Akhurst and G. Owen of the Rubber Research Institute of Malaya. They have confirmed the high acidity of the deep lying grey sediment. High acidity and high contents of sulphur in present-day lowland soils have been recorded in Malaya by R. G. H. Wilshaw (1940) and by J. K. Coulter (1952) and in Uganda by E. M. Chenery (1952, unpublished observation). J. A. Prescott and R. L. Pendleton (1952) mention the high acidity of marshes in Western Australia which is associated with the oxidation of ferrous sulphides such as marcasite and which may have some bearing, they consider, on the origin of laterite. Prescott and Pendleton also note indications that gallium, molybdenum, lead, vanadium and zinc may be segregated with iron in laterite. It is evident that weathering by sulphuric acid may be found to have considerable practical and scientific interest.

Dr. Elizabeth Alexander has noted rapid removal of silica in Singapore and suspects that silica dissolves and separates from solution much more rapidly than has been supposed. Satisfactory supporting evidence is still awaited and would be received with great interest because we do not yet have a clear understanding of the conditions that lead to removal of silica which is characteristic of the type of weathering that has been called lateritic.

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

Soil surveys have been started this year of sheets 107 (Denbigh) and 280 (Wells) and work has been continued on sheets 75 (Preston), 70 (Leeds), 188 (Cambridge) and 238 (Aylesbury). In spite of changes of staff and the beginning of new surveys, excellent progress has been made so that altogether 147,000 acres have been mapped in detail on the 6 in. to 1 mile scale.

During the year Dr. G. Smith of the United States Soil Survey spent a considerable time in Great Britain and other countries of Europe, visiting the areas being surveyed with a view to correlating the higher soil classification units used in the various countries with those in use in the United States. Professor W. Kubiena, who is well-known for his work on micro-pedology, was invited by the Agricultural Research Council to visit this country for two months to give us the benefit of his wide experience both in the field and the laboratory. Resulting from an arrangement for the exchange of soil surveyors, Mr. B. W. Avery left for New Zealand in exchange with Mr. E. Cutler and will study soil survey methods in use in that country.

Hertfordshire and Buckinghamshire

Sheet 238 (*Aylesbury*)

Detailed surveying has been extended in a north-westerly direction from the forest and common land around Ashridge which was surveyed last year and the soils of about 27,000 acres have been mapped; only one new series—the Berkhamsted—was set up. The soils of the area are developed on Chalk, Clay-with-Flints and Pebbly Clay and Sand. On the scarp and along the steep valley sides carved from the Upper and Middle Chalk and extending down to the Totternhoe Stone in the Lower Chalk, is the Icknield series. The soils are usually thin and generally consist of a black or dark brown crumbly loam passing via broken chalk to the solid chalk. The Lower Chalk, with a much higher clay content, gives rise to two series, the Wantage and the Burwell, both consisting of moderately deep, calcareous, grey-coloured clay or clay loam soils and differentiated by their drainage characters, the Wantage being better drained than the Burwell in which yellow and brown mottlings are apparent.

The commonest soil on the plateau is the Batcombe which has a pale brown, slightly acid, loamy surface soil of moderate depth passing to heavier red-coloured clay or clay loam of the Clay-with-Flints. Where the loamy surface soil is missing, probably owing to erosion on steep slopes, the red or orange clay is exposed at the surface and the imperfectly drained, slightly calcareous clays and clay loams of the Winchester series are found. These soils also occur on flat areas. On steep slopes erosion has frequently reduced the thickness

of the Clay-with Flints and the solid Chalk is within easy reach of the auger; these grey-brown to brown, calcareous, flinty clay soils belong to the Wallop series.

At the foot of valley slopes covered by the above soils, colluvial material, derived from the Chalk and Clay-with-Flints, gives rise to the Coombe and Charity series which are not easily distinguished from each other. Both are variable in texture but the Charity soils contain fewer flints and are neither as calcareous nor as brown as those of the Coombe series. In the centres of the valleys there is often an organic silty loam overlying gravel that extends considerably further north-west than the present spring-heads.

The Pebbly Clay and Sand around Little Heath gives rise to the Berkhamsted soil with a freely drained, dark brownish grey, very stony, sandy loam overlying dark brown, very stony loam passing to vari-coloured loamy coarse sand over clay.

Yorkshire

Sheet 70 (*Leeds*)

No new series were defined in this area where about 11,000 acres were mapped on the Magnesian Limestone and Millstone Grit formations. Owing to the fact that a considerable time was spent in mapping restored open-cast coal sites at the scale of 25 in. to 1 mile, a smaller area than normal has been mapped. In the restored open-cast coal site survey, mainly in Derbyshire, attempts were made to classify the sites on drainage, erosion and root development characters as well as on the actual soil conditions.

In the area of primary survey aerial photographs are being used to see how much useful information can be obtained from them. The interpretation of air-photos is difficult in a country like Great Britain, where the land-use pattern is man-made and greatly obscures the detail which would be of use to the soil surveyor. However, a map made of an area from photographs bore a resemblance to the one made by previous field workers who did not use them. A map of another area made in a similar way will be checked by field work during the coming season.

Somerset

Sheet 280 (*Wells*)

This sheet borders the northern edge of the completed Glastonbury sheet and extends nearly to Weston-super-Mare and Chelwood. The area can be conveniently divided into three physical regions: (1) the low-lying moors in the south-west and a similar smaller area in the north-west; (2) the Mendip Hills which extend diagonally from south-east to north-west and (3) the " hill and valley " district north-east of the Mendip Hills. The whole area includes rocks of Silurian, Devonian, Carboniferous, Triassic and Jurassic ages as well as peri-glacial deposits on and around the Mendip Hills and a considerable extent of recent alluvial deposits including peat. So far about 14,000 acres have been mapped mainly along the southern edge of the sheet.

Almost all the series encountered have been mapped and described in earlier work but two new series—the Moon's Hill and

the Knapp—have been recorded on andesitic lava and tuff of the Silurian age respectively. The Moon's Hill series is a thin, freely drained soil having a dark brown, light loam surface soil with a loose crumb structure overlying a lighter brown gritty loam. The andesitic rock is very soft to a considerable depth. Associated with the lava is a gritty silty clay deposit believed to be tuffaceous material. The Knapp series formed on it is a poorly drained soil having a surface soil of about 6 in. of dark grey loam to clay loam. This overlies about 3 in. of pale grey clay loam which passes to a very variegated silty clay with rounded andesitic grit.

A soil intermediate in drainage between the very poorly drained Birtsmorton series and the imperfectly drained Worcester series has been tentatively named Wellesley and may be correlated with the Spetchley series previously described in Worcester. The profile consists of about 9 in. of dark grey-brown mottled clay loam passing to red-brown Keuper Marl with mottling throughout.

Lancashire

Sheet 75 (*Preston*)

A further 25,000 acres have been mapped south of the Ribble estuary and along the eastern margin of the sheet on the foothills and moorlands around Tockholes, Darwen and Blackburn to Walton-le-Dale. In the west, between Banks and Becconsall and also north of Bretherton the former thin cover of peat has disappeared either by cutting or by cultivation, and the present profiles show a peaty heavy loam surface overlying a grey gley horizon which passes to the heavy Triassic till at about 24 in. Adequate artificial drainage has given these soils their high agricultural reputation. In many places estuarine deposits overlie peat or the till, in which old soil profiles can be seen, while in other places the till is exposed and the normal soils associated with it are found. The well-drained cultivated soils within the old embankments along the Ribble and Douglas constitute some of the best cropping land and have been mapped as a complex, the predominating soil of which has a fine sandy silt surface soil overlying silty fine sand. Traverses have also been made across the outer marsh which is now used for grazing and where there is a general tendency for the soils to contain more fine sand towards the north-west.

In the moorland, the previously established complexes have been used as mapping units as well as soil series identified earlier. One new series, tentatively named Tockholes, has been found on sandy shales and fine-grained shales and sandstones of the Coal Measures and Millstone Grit formations. The profile shows a grey-brown loam or sandy loam surface soil passing to yellow-brown sandy loam in which the proportion of sandstone and sandy shale fragments increases with depth. The more gently undulating country around Hoghton and Walton-le-Dale is covered by mixed Triassic and Carboniferous till on which the most extensive series is the Coppull.

An interesting feature of the soils found on Triassic and mixed till is the presence, at depths of from 42 in. to 60 in. of calcareous concretions and deposits on the faces of structural elements. Examination of deep cuttings in many parts of west Lancashire shows this

to be a general feature of the soils developed on till of Triassic or partly Triassic origin.

Cambridgeshire

Sheet 188 (*Cambridge*)

During the season approximately 32,000 acres were surveyed, the greater part of which forms an irregular strip about four miles wide running east from Willingham and Long Stanton St. Michael to the river Cam where it continues eastward to near Reach and Wicken and northward to Podney, Soham Mere and Soham. The countryside is featureless and nowhere rises above 50 ft.; nevertheless it is lithologically diverse and contains soil parent materials with a wide range of textures.

The fenlands, through which the Cam flows from south to north, are the main feature of the area and peat of the Adventurers' series up to 9 ft. thick, and associated pond silts and shell marls overlying deep peat, form a band up to ½ mile wide traversed by the river whose artificial course is flanked by very recent alluvium. A complex group consisting of shallow peat, peaty loam and organic loam soils overlying weathering chalk marl. Gault clay and river loams occurs to the east of this fenland while similar soils on river loams and silts appear on the western margin.

East of the Cam are outcrops of Corallian limestone and Gault clay. The former gives rise to a shallow soil of the red and brown calcareous soil group while on the Gault and its associated drift are found the slightly gleyed Peacock and Newbarn series with smaller areas of other series. Between the two groups of soils lies the calcareous lake clay which formed the bed of the now vanished Soham Mere.

In the neighbourhood of Cottenham and Willingham the Gault and the similar Kimmeridge and Ampthill Clays give rise to soils mainly of the Peacock and Newbarn series while a brown earth of medium texture is developed on the Lower Greensand. North of Waterbeach occurs a complex of well-drained calcareous loams which, to the north and north-west merges into a complex of less well-drained loamy soils around Chittering. The river Ouse flows along the northern boundary of the area and shallow peat soils and recent alluvium are found adjacent to it. A small area of peat and gleyed sands and loams was mapped near Little Wilbraham.

Denbighshire

Sheets 107 (*Denbigh*) *and* 95 (*Rhyl*)

Detailed mapping has been started on these sheets and 38,000 acres have been surveyed in two areas, one including parts of the parishes of Llaneilian-yn-Rhos, Bettws Abergele, Llangeruiew and Wenlli, the other covering the land between Llansannan and Henllan and the moors on the southern edge of the map. Except for the coastal plain and the Vale of Clwyd the topography of the sheets is one of the high relief, much of the land in the south being over 1,000 ft. O.D. and several hills near the coast attain this height. Scarp ridges and steep sided valleys are a characteristic feature of the landscape. Most of the central district is drained by the Aled

and Elwy and their tributaries which enter the Clwyd near Rhuddland. The Ystrad and Clywedog drain into the Clwyd from the south-east corner while the north-west is drained by the Dulas which enters the sea near Llandulas.

The greater part of the area is underlain by Silurian shales and grits, forming a monotonous series of hard non-calcareous clays and silt shales with occasional grits, whose faulting has largely determined the complex relief. A narrow belt of Carboniferous Limestone roughly divides the elevated shale country from the lower-lying ground to the north-east in the Vale of Clwyd. Basement beds of red micaceous sands and marls are associated with the limestone but are rarely sufficiently exposed to influence the soil. There are small outcrops of Coal Measures and Triassic sandstones in the Vale, but, like most of the Vale, they are also largely covered by deep drift. A large tract of marine alluvium extends from Abergele to Prestatyn; the alluvium of the Clwyd floodplain is mainly derived from Silurian shale.

In the areas mapped only a small number of series has been encountered and all, except two, have been described previously. It has been found necessary to describe phases of the Penryhn series, some of which may be given series rank later. The Aled series is a freely drained soil developed on shale alluvium whose profile consists of a brown to yellow-brown loam overlying a very stony gravel bed. The depth at which the gravel appears greatly influences the agricultural value of the soil with regard to summer drought. In all cases where this trouble occurred, the gravel was within a few inches of the surface. An as yet unnamed series developed on grey, compact shale drift and always found on the tops of smooth features also suffers from summer drought and may be temporarily waterlogged in winter owing to the impervious nature of the underlying drift. The profile usually consists of 9 in. of grey-brown light loam to loam with a sharp transition to the compact, slightly mottled, unweathered drift.

MICROPREDATORS IN SOIL

By

H. G. Thornton and L. M. Crump

Introduction

The growth and health of crops is greatly affected by the activities of the soil micropopulation so that the factors that influence the size and composition of this population are a fundamental interest in soil science. The quantity of living matter comprising the soil population is, of course, determined and limited by environmental factors such as the quantity and availability of food material and such variables as pH, moisture, aeration and temperature. But the dominance of certain groups of organisms in the soil population and the prevalence of organisms having specific effects, whether beneficial or harmful, are of far greater importance than is the total size of that population. Here again factors external to the population itself must ultimately determine its biological composition. In this case, however, their action may be indirect, for the varied organisms comprising the micropopulation interact in a very complex manner, so that the effect of an external agent on any one of them may be influenced by its effect on the other organisms. Any attempt therefore to produce a beneficial change in the soil population, whether it be the encouragement of organisms producing desirable biochemical changes or the discouragement of harmful organisms such as pathogens, must involve knowledge of the interaction of such organisms with their associates and competitors in the soil. Competition between organisms in the soil takes place in three principal ways. Firstly, there is a keen competition for the limited supply of available nutrients. Secondly, there are the toxic effects of the products of growth of one organism on others, of which the action of specific antibiotic secretions is an example. This may be quite incidental in that the organism producing them may gain no benefit other than some possibly increased freedom from competition. Thirdly, there are organisms that feed directly upon others as their only or main method of nutrition. These organisms may conveniently be called "micropredators." There are a few organisms remarkable for their modes of nutrition such as fungi that attack nematodes or amœbæ, and the recently described rhizopod protozoa that consume nematodes, but the great majority of micropredators in the soil feed on bacteria. They include protozoa, the active stages of certain myxomycetes and also some Myxobacteria that feed by dissolving bacterial cells and absorbing the products of lysis. There are also some small metazoa such as nematodes that eat bacteria but the work summarized in this report deals only with micropredators having an active unicellular stage.

Interest in soil protozoa has long been maintained at Rothamsted and dates from the work of Russell and Hutchinson on partial sterilization of soil (1909), and their suggestion that, in untreated soil, the numbers of bacteria might be limited by the feeding activities of soil protozoa and that the destruction of the latter might

account for the observed increase in the number and activity of bacteria in soil after partial sterilization. This theory instigated work at Rothamsted on soil protozoa by T. Goodey from 1910 to 1913, the late Martin and Lewin from 1913 to 1915, Crump who came here in 1915, Cutler who came in 1919 and others who came later. The Protozoology Department was set up in 1919 under the leadership of Ward Cutler originally to study the protozoan fauna of soil, although its scope was later widened. Investigation at Rothamsted and elsewhere showed that soil contained a large and varied protozoan population, amongst which amœbæ and flagellates were predominant, and also that the protozoa existed in an active condition in field soil. This discovery, coupled with the theory of Russell and Hutchinson, made it important to find out whether the numbers of bacteria in soil were controlled by the feeding activities of protozoa. It was therefore necessary to determine what relationship the numbers of bacteria in field soil have to those of the active protozoa.

A technique was devised for the estimation of numbers of protozoa that fed on bacteria, based on a series of soil dilutions (Cutler, 1920), and the plating method for counting soil bacteria was improved. Preliminary counts showed that the numbers both of bacteria and of protozoa changed at short intervals in field soil. In 1920-21 therefore, a series of soil samples was taken from the Barnfield dunged plot at daily intervals for a year and the numbers of bacteria and of the active and encysted individuals of two species of amœbæ and four of flagellates were estimated. (Cutler, Crump and Sandon, 1922.) Marked fluctuations in the numbers of bacteria and protozoa are found ; these were not clearly related to weather conditions but there was a general rise in all groups during the spring and autumn. Changes in bacterial numbers were not related to those of the flagellates. Of the two amœbæ, one, then identified as Dimastigomœba, was much the more abundant in most samples. The frequency of occurrence of high numbers of the active form of this amœba (above 100,000 per gram of soil) was significantly related to that of low bacterial numbers (below 30 millions per gram). This indicated that the amœbae when sufficiently numerous exercised a controlling effect on the changing numbers of bacteria found in the plot by the plating method used. Experiments also showed that amœbæ did keep down the numbers of bacteria when both were inoculated into sterilized soil (Cutler, 1923).

In 1941, on the death of Mr. Ward Cutler, the department was merged with that of Bacteriology to form the present Soil Microbiology Department and it is with the work carried out since then that this summary is mainly concerned.

The selective feeding of soil protozoa

At the time when the surveys of bacterial and protozoan numbers in Rothamsted field soil were made, the quality of the bacterial food supply was not considered, but somewhat later work, both at Rothamsted (Cutler and Crump 1927 and 1935) and elsewhere, showed that soil bacteria differ in their edibility by protozoa. But it was important to discover whether amœbæ, supplied with a mixture of bacterial species, as happens in fresh soil, will feed selec-

tively and whether they can in consequence change the relative numbers of different bacteria in the soil. B. N. Singh investigated the feeding of amœbæ and of a flagellate on different species of bacteria using an ingenious method in which an inoculum of amœbæ placed at the centre of an agar surface in a petri dish, was presented with a series of radially disposed streaks of different bacterial species whose subsequent rate of consumption could thus be compared. In his first series of experiments (1941a) he tested two species of soil amœbæ on five strains of Aerobacter, and twelve species of soil bacteria; in his second series (1942) two amœbæ and the flagellate Cercomonas were tested on sixteen strains of the nodule organism Rhizobium, twenty other assorted species of soil bacteria and twelve species of plant pathogenic bacteria; in his third series (1945) two amœbæ were tested on sixty-three species of soil and thirty-nine of other bacteria. The species of soil bacteria tested in these experiments differed widely in their characters. About half of them were eaten by the protozoa and showed a range of edibility from some that were readily and completely consumed to others that were but slightly attacked. There were small differences between the two species of amœbæ and rather larger differences between the amœbæ and the flagellate in respect of the particular bacterial species that were eaten. Amœbæ when placed in contact with closely adjacent parallel streaks of readily and less readily eaten species of bacteria usually consumed the whole of the former before making a noticeable inroad on the less edible species. They could, however, be adapted by previous feeding on the less edible species and would then eat both species together. Of eight species of bacteria producing red or pink pigment, seven were not eaten, nor were strains of *Chromobacterium violaceum* or *Pseudomonas æruginosa*. Apart from this relationship to pigment, no clear relationship emerged between the edibility of a bacterial species and any other of its characters, such as gram staining, or slime production.

Species that are eaten differ greatly in their nutritive value as measured by the multiplication rate and by the mean cell size of protozoa fed on them. This was shown, for example, with amœbæ in early work of Cutler and Crump (1927) as more recently for a ciliate by Singh (1941b). Some bacterial species produce secretions highly toxic to amœbæ (Singh 1945). A number of these produce pigments and, in several cases studied, the pigment itself was found to be toxic. This was the case with pyocyanin, prodigiosin and the violet-blue pigment of *Chromobacterium violaceum*.

Not only is the total number of amœbæ affected by the quality of the bacterial food supply but also the percentage of them that is in the active condition. For not only do they tend to form cysts in the presence of unfavourable bacterial food, but Crump has shown that with some species of soil amœbæ, hatching of the cysts is stimulated by the presence of bacteria of which the correct species must be present to ensure maximum excystment (1950).

A highly specific relationship between soil amœbæ and bacteria can thus be demonstrated on laboratory media, and Singh showed that amœbæ are also specific in their consumption of bacteria in soil (1941a). He inoculated samples of sterilized soil with two species of bacteria each in pure culture and with both species together,

with and without the further addition of soil amœbæ. In the absence of amœbæ, the bacteria fluctuated greatly in numbers in a manner previously observed under similar conditions by Taylor (1936). In the presence of amœbæ, however, one species of bacterium was greatly reduced in numbers and eventually almost extinguished. The other less edible bacterium was little affected and after a month had regained the numbers found without the amœbæ. Thus the amœbæ were able in soil to alter the relative numbers of the two bacterial species.

It seems likely therefore that quality of bacterial flora in differently treated field soils may both influence the numbers of amœbæ and be itself influenced by their selective feeding. That the nutritive quality of the bacterial flora to amœbæ does in fact differ with soil treatment is suggested by counts from field plot samples described below.

Improved method for estimating the numbers of amœbæ in a soil sample

Our knowledge of the soil population is limited by the adequacy of our methods for estimating the numbers of organisms belonging to each of the different groups of which it is composed. Methods for doing this involve making a suspension of the soil sample and, in most cases, diluting this suspension to known degrees. Direct microscope counts are only possible for groups, such as bacteria, present in very large numbers. Otherwise a less direct method must be used. If the organisms to be counted will grow as colonies on a jelly medium, the numbers present at certain known dilutions can then be counted by plating methods.

But important groups such as the protozoa will not do this satisfactorily and here we can only base our estimate on the presence or absence of the organisms in samples from a series of dilutions. Such samples are incubated under conditions ensuring growth of the organisms by which growth their presence is detected. With amœbæ these conditions include the supply of bacteria edible by them. Selective feeding tests showed that strains of Aerobacter were readily eaten by a range of species of amœbæ and other soil protozoa and this knowledge enabled Singh (1946 a and b) greatly to improve the counting method by using as food supply a pure culture of Aerobacter placed in a petri dish on the surface of non-nutrient agar or silica jelly, on which possibly harmful or inedible bacteria from the soil dilution would make little or no growth. The accuracy of estimates by the dilution method is dependent on the number of replicate samples at each dilution that are examined. This was increased by using, for each dilution to be examined, a petri dish in which eight small glass rings were imbedded in the agar or silica jelly, in each of which a sample of the dilution was tested for the growth of amœbæ on Aerobacter.

This improved technique gave consistent results between duplicate samples from field soils, but " recovery " tests from sterilized soil to which known numbers of amœbæ were added showed a consistent loss of about 30 per cent, most of which could be accounted for by non-viability of individual amœbæ in laboratory culture. Thus counts from soil probably represent a systematic underestimate of this order, inherent in any cultural method of counting.

The numbers of amœbæ and bacteria in differently treated plots

The above technique has been used by Singh to survey the content of active and encysted amæbœ (1949) in plots on Barnfield and Broadbalk and in partially sterilized field plots at Ampthill, Bedfordshire. The samples examined from Barnfield and Broadbalk were taken at nine and six approximately monthly intervals respectively from the plots with no manure (8·0 and 3) farmyard manure (1·0 and 2) and complete artificials (4A and 7) in each field. Over the periods of sampling marked fluctuations in numbers of amœbæ took place. In both fields the numbers of amæbœ, both total and active, were much the lowest in the untreated plots but did not differ appreciably as between the plots treated with farmyard manure or artificials. On the other hand bacterial numbers, determined by both microscope and plate counts, from the same Broadbalk samples by Skinner, Jones and Mollison (1952) were much higher in the farmyard manure plot (2) than in the other two plots (3 and 7), whose bacterial numbers were similar to each other. In other words the ratio of the number of amœbæ to those of bacteria was much higher in plot 7 than in plot 2. This suggests a qualitative difference in food value to amœbæ of the bacterial populations in the two plots.

The setting up by the Chemistry Department of a plot experiment at Ampthill, Bedfordshire, to test the effects of partial sterilization on Sitka spruce nursery beds gave an opportunity to study its action on soil protozoa in the field. An untreated plot and plots whose soil had been partially sterilized with steam and with formalin were sampled at intervals after the treatment and the numbers of bacteria and of amœbæ were estimated by Crump and Singh (1953). Both treatments caused an immediate fall in the numbers of amœbæ and bacteria, the latter estimated by plate counts. After this, in the steamed plot the numbers both of amœbæ and of bacteria rose far above those in the untreated plot. But after formalin treatment the number of bacteria rose well above those in the untreated plot but numbers of amœbæ remained persistently depressed. This result shows that the effects of soil partial sterilization on the micropopulation differ according to the type of treatment used. This conclusion is supported by the different effects produced by steam and formalin on the fungal population of the plots (Mollison 1953).

Classification of soil amœbæ

A difficulty constantly met with in studying the soil protozoa is that of identifying them. Correct identification is of added importance because of the specific reactions which different amœbæ show towards soil bacteria. The taxonomy of small amœbæ was hitherto based to a large extent on characters too uncertain to be of practical value, such as the occasional production of flagella. The type of nuclear division is a more stable character and differs strikingly between different groups of amœbæ, but the difficulty in finding specimens of the different stages of nuclear division has until now limited the usefulness of this character. The discovery of a satisfactory bacterial food supply for cultures of soil amœbæ enabled Singh to devise a beautiful and simple technique in which

thick cultures of these amœbæ including all stages of nuclear division can be grown on cover slips coated with films of agar supplied with suitable bacterial food (1950). A fortunate habit of the amœbæ to wander through the agar on to the glass surface enables the agar to be removed and the amœbæ to be left adhering to the cover slip, where they can be fixed and stained. With this method he has studied the nuclear division of a number of soil amœbæ and has proposed a classification of amœbæ based on this character (1952).

Giant Rhizopods from soil

The use of a generally edible bacterial food supply for counting amœbæ and for isolating them from soil, resulted in several other types of bacterial predators appearing in cultures from field soil. One of these was a giant multinucleate Rhizopod of the genus Leptomyxa which may attain a diameter of nearly 3 mm. The history of work on this organism is interesting. In 1913 T. Goodey, who was then studying soil protozoa at Rothamsted, found and described three Rhizopods of a type new to the soil fauna and related to the Proteomyxæ. On these he founded the two genera Leptomyxa and Gephyramœbæ (Goodey 1915). Sandon in 1927 found Gephyramœbæ in several soil samples in the course of a survey of protozoa from a range of soils. He however failed to find Leptomyxa although this organism was again found in Australian soil by McLennan in 1930. After this it was not recorded again until Singh (1948a), using Aerobacter as food supply, found that it could be isolated regularly from field soil and obtained it from thirty-eight out of fifty-nine soil samples derived from localities widely scattered over Great Britain and from nine of the plots on Barnfield and Broadbalk. He studied its life-cycle and nuclear division (1948b) and showed that like true amœbæ it was selective in its bacterial food requirements but differed from the amœbæ with which he compared it, in the species of bacteria that it would eat (1948a). A few estimates made by the dilution method from the soil of Barnfield plot 1·0 revealed its presence in dilutions up to 1/1,000.

Soil Acrasieæ

The improved methods of culture used for soil Rhizopods also revealed the abundance and widespread occurrence in soil of a second group of amœboid Protista, the Acrasieæ, particularly the genus Dictyostelium, which was first described by Brefeld in 1869. Singh obtained this organism from soil samples collected from widely scattered localities in Great Britain. He found it in 33 out of 38 arable soils examined but only in 3 out of 29 grassland soils (1947a). He also found it in all the plots from Barnfield and Broadbalk. The Acrasieæ pass through a remarkable life cycle, in one stage existing as amœba-like forms, " myxoamœbæ," which later, under suitable conditions, collect together and form fruiting bodies superficially resembling those of certain fungi. Inside these, spores are formed which are released and from which the amœboid forms are hatched. In the amœboid stage they feed on bacteria and in this stage Dictyostelium, like other predators, was found to be specific in the species of bacteria that it would attack (1947a and b). It

will also develop and form fruiting bodies when grown in sterilized soil supplied with suitable bacterial food and was then found greatly to reduce the numbers of bacteria in the soil (1947b). The growth of the organism in sterilized soil as judged by the development of fruiting bodies on the soil surface, was found to be dependent on the species of bacteria supplied. The spread of the organism through the soil was dependent on its moisture content. There was little evidence of spread at moisture contents below 25 per cent, and below 15 per cent moisture no fruiting bodies were found even at the point of inoculation, perhaps because the amœboid forms could not assemble in such dry soil. The organism will also pass through its life cycle in fresh unsterilized soil.

Soil Myxobacteria

The Myxobacteria were recognized as a group by Thaxter in 1892 but the group has been comparatively little studied till recently and even now many forms are known only by their fruiting bodies. The more highly developed types of Myxobacteria pass through a life-cycle. In the active stage they consist of thin rods, capable of a sliding motion the mechanism of which is not understood. After a while these rods collect to form swarms each of which may become covered with a coating to form a fruiting body. Inside this the rods turn into the so-called " microcysts " which are usually round or oval bodies but which in some species have the form of short rods. They are eventually released and develop into the active rod stage. Some of the Myxobacteria found in soil do not swarm to produce fruiting bodies. Important amongst them is a group attacking cellulose and placed in the genus Sporocytophaga (Stanier 1942), which was originally found and studied at Rothamsted in 1912 by Hutchinson and Clayton, who mistakenly considered them to be Spirochætes. Another genus, Cytophaga (Winogradsky), even lacks the microcyst stage. Some species in the genus also attack cellulose while others have a more generalized nutrition. One of these that can attack chitin, was isolated by Stanier (1947) during a short visit to Rothamsted. The " higher " Myxobacteria from soil, that have been studied by Singh, belong to the genera Myxococcus, Chondrococcus and Archangium. These organisms are micropredators since they feed readily on true bacteria previously killed and dissolved by their secretions. In a joint investigation Oxford and Singh (1946) found that Myxococcus produced two types of secretion one of which had a toxic effect on a considerable range of bacterial species while the other was a powerful bacteriolytic and proteolytic enzyme that would lyse dead bacteria, though not attacking live ones. Myxobacteria of this predator type are again selective in the bacterial species which they will attack (Singh 1947c). At one time they were regarded as dung inhabiting organisms but they have been found to be widely distributed in British soil and to occur in all the various plots of Barnfield and Broadbalk most of which do not receive dung, so that their status as soil inhabitants is no longer in doubt. Dilution counts from the soil of Barnfield plot 1·0 gave numbers of predaceous Myxobacteria ranging from 2,000 to 76,000 per gram.

Conclusion

There is no means of estimating the effect on the bacterial flora of soil of the micropredator population as distinct from other competitive and antagonistic factors. The daily counts of amœbæ and bacteria from Barnfield made by Cutler, Crump and Sandon (1922) showed evidence of a limitation of bacterial numbers when the number of amœbæ in an active state exceeded 100,000 per gram of soil. In view of the variety of other micropredators now known to inhabit the soil it is not surprising that the effects of any one gronp such as the amœbæ should be distinguishable only when present in exceptionally high numbers. Any assessment of the quantitative effect of the micropredators as a whole would require that the numbers of each type should be estimated from a range of soil samples and compared with bacterial counts. Such a task is at present beyond the capabilities of our counting technique.

But the selective attack on different bacterial species, evidence for which has been found with all groups of micropredators, adds greatly to their interest from the point of view of soil ecology. Singh tested eighty-seven very varied strains of soil bacteria against eight micropredators, comprising a large and a small soil amœba, the giant Rhizopod *Leptomyxa reticulata* Goodey, the myxamœbæ of two species of Acrasieæ (Dictyostelium) and three species of predaceous Myxobacteria (Anscombe and Singh 1948). Any one of these predators was found to attack about half of the bacterial species tested, but owing to the dissimilarity in feeding habits of the various predators there were only seven of the bacterial strains that were not attacked by any of the predators and only twelve were attacted by all of them. Certain groups of bacteria such as the nodule bacteria seem to be generally resistant to attack by micropredators while others such as strains of Aerobacter are attacked by all of them. If it is desired to establish any kinds of bacteria in soil, their resistance to predators should be considered. The presence of micropredators also complicates the unravelling of the effects of soil treatments and especially those like partial sterilization that are liable to check the predators. This was appreciated by Russell and Hutchinson in their original hypothesis although this now appears to us as an over-simplification of the complex perturbations that must occur when the balance of micro-organic life is radically upset by soil treatment.

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LARGE-SCALE PRODUCTION of EDIBLE PROTEIN from FRESH LEAVES

By

N. W. Pirie

The study of plant viruses is the study of leaf protein; for not only are all the known viruses proteins, but to purify them it is necessary to separate large amounts of normal leaf protein from the preparation. Since 1934 we have been engaged in this work and, during the succeeding years, have become increasingly interested in the proteins of the normal leaf. In part this interest was stimulated by war-time food shortages which made it important to see whether leaf proteins could be used as human food and in part it was the result of a recognition of their intrinsic biochemical importance. The study of animal viruses was preceded by a fairly detailed knowledge of the properties of animal proteins and the behaviour of tissue extracts, but during the early phases of work on plant viruses much more was known about the soluble proteins of the infected tobacco leaf than about those of the normal leaf.

The idea that extracted leaf protein could be of nutritional and industrial importance is not new (c.f. Pirie 1942 a and b) and when work, in collaboration with the Food Investigation Board and Imperial Chemical Industries, started in 1940 there was some past experience to build on. Several patents covering leaf-protein preparation had been taken out, some of them dealing with phenomena that have been well known since the pioneer studies of Rouelle* in 1773, but all the experience had been gained on the laboratory scale. No method had been worked out for handling more than a few pounds of leaf and it seemed likely that the conversion of laboratory-scale extractions and fractionations into a large-scale process would prove difficult. It was easy enough to see what we were trying to do; the only problem was how to do it.

During 1940 and 1941 therefore, a series of extraction tests was made with full-sized mills of many types. At first these tests were based on the crudest empiricism but a few principles soon began to emerge. On the one hand significant amounts of protein are not brought out of the leaf by simple pressure, but on the other hand it is not necessary to open each cell. Fine subdivision is indeed, a disadvantage because it is more difficult to separate leaf fragments from the dispersed protein the smaller the fragments are. Some subdivision, coupled with intimate rubbing and bruising of the leaf, releases much of the protein, and the rubbing is done as well by rubbing leaf on leaf as by rubbing the leaves between two elements of the machine. As in most large-scale operations the process should be continuous both in theory and practice. The distinction

* Those who have worked on leaf protein recently have not been deeply interested in the history of science and have not devoted much attention to Rouelle nor even given his initials. I have in the past erroneously attributed this work to G. F. Rouelle but it was, in fact, done by his younger brother Hilaire Marin who succeeded to the demonstratorship at the Jardin du Roi in Paris on the elder Rouelle's death in 1770.

is important, for some mills seem to be working continuously when they are, in fact, filling up with resistant pieces of fibre, and this may not be recognized on short runs. The mill must cope with occasional stones for these will inevitably accompany agricultural crops. Power consumption must be kept down both for economy and to avoid over-heating the charge. Unless a wasteful cooling system is to be used, it is clear from first principles that the limit comes at about 50 HP for a grinding rate of 1 ton of wet crop per hour. Preliminary drying or adding large amounts of water to the crop are both to be avoided if possible.

This much became clear by 1942 but then work along these lines was stopped. The reasons for this decision were never made clear; it is not, therefore, possible to express an opinion on their validity. At Rothamsted, however, work continued on the laboratory scale and the results were systematized by Crook (1946) who finally managed to extract 95 per cent of the protein in tobacco leaf by very fine grinding and by maintaining mild alkalinity and low salt concentration. Crook and Holden (1948) and others at Rothamsted, using similar techniques, have separated protein from about thirty different species of leaves in varying yield, and we now have enough experience to be able to tell from the appearance and feel of a leaf what its protein content, and the extractability of that protein, is likely to be. This work was done with the idea of large-scale extraction directly in mind, but much of the other work of the Biochemistry Department also gives information about the separation and fractionation of proteins from the leaf. Work on viruses and on pectase, protease, cellulase, normal nucleoprotein and enzymes concerned in the oxidation of manganese has been described in successive Annual Reports; we have also described the action of commercial proteolytic enzymes on leaf fibre and the effect of fertilizers on the protein content of the leaf.

Protein is held in many different ways in the leaf and when one particular leaf enzyme is being studied selective methods of extraction are an advantage. When, however, a bulk protein preparation is wanted it is an advantage to get all out in one operation. Protein is held in the leaf in three main ways. It may be dissolved in the fluids liberated when the cell structure is damaged by grinding; it may be present in the chloroplasts, nuclei and other microscopically recognizable cell components; it may be in the cell walls. The intensity of grinding will influence the composition of the mixture by varying the extent to which these components are released. The nutritional and physiological state of the leaf will also effect the composition of the isolated protein, because they affect the ratios in which some different enzymes occur (Holden and Tracey 1948) and it is reasonable to assume that the protein is largely made of enzymes.

For practical purposes a protein may be said to be in solution if it does not settle out under gravity in a few hours. Much of the protein in a leaf extract is soluble initially but coagulates after a few hours at room temperature. Many actions are probably involved in this coagulation; some proteins are so associated with enzymes as to be intrinsically unstable (Pirie 1950) some are probably clotted, as milk is, by leaf proteases (Tracey 1948), while some combine

with tannins and other leaf components and precipitate slowly. Changes of this type probably also go on quickly and may be responsible for some of the readily sedimentable protein in extracts. Chloroplasts and chloroplast fragments are easily separated from the fibre of many leaves and these may make up the greater part of the readily sedimentable protein in some extracts. In some leaves, however, the chloroplasts do not readily separate from the leaf matrix and in some, precipitation by tannins is so rapid that part of the protein remains in the fibre. Holden and Tracey (1950) have discussed the necessity for assuming that any significant amounts of protein are held in the cell walls. They found that the ratio of nitrogen to chlorophyll is nearly the same in isolated chloroplasts and in washed tobacco leaf fibre. There is no reason to think that protein in the cell wall would be associated with chlorophyll. It is probable, therefore, that most of the introgen remaining in the fibre is present as entangled chloroplasts and chloroplast fragments. Suggestions have been made that part of the lignin of the leaf contains nitrogen, but the total amount that is held in this way is small.

In 1948 a grant from the Agricultural Research Council enabled large-scale work to start again and the survey of existing machinery was continued. Ten different designs of swing-hammer mill were tested under varying conditions and the conclusion was reached that this method of grinding was not suitable because it depends on impact between an unsupported particle and the moving hammer. Wet leaves are not shattered by this type of impact. Designs in which a compacted mass is rubbed or has bars forced through it, as in the domestic meat mincer or the screw expeller, are satisfactory on a small scale but, because the ratio of surface to volume changes when the scale increases, they consume excessive amounts of power when the scale is increased. The idea of continuous rubbing however, was attractive, so having found that none of the existing mills would handle the soggy dough-like mass that results when fresh leaves are ground, a mill was designed that cannot clog and is adjustable to the texture of the material being used.

The basis is a Christy and Norris "coir sifter," designed to separate coconut husk from fibre, and is a drum 4 ft. 6 in. long and 3 ft. in diameter with an axial shaft carrying plain rectangular beater arms. It was fed tangentially at one end and discharged radially at the other. Now it is fed axially at one end and discharges tangentially at the other, many more beater arms have been introduced, so that no space inside the drum more than $\frac{3}{4}$ in. wide is left unswept by an arm, and the arms have been modified so that some have propellor-shaped ends and the others U-shaped ends. By varying the ratio of these two types, the rate of movement of the charge through the machine can be controlled to get the correct amount of grinding. There is no obstruction at the exit; material comes out whatever its state of grinding when it has traversed the mill. This is an important distinction from most types of hammer mill because the charge generally has to stay inside until it has been ground fine enough to get through a screen. Ground leaves soon choke a screen.

The primary merit of this machine is that it works and has run for many hundreds of hours at the Grassland Research Station

without a breakdown. But it is a makeshift and the next one should be designed from the beginning rather than adapted from an existing machine. It should be smaller, it should be so arranged that it can be opened and cleaned easily, and it should be easy to rearrange the distribution of the two types of beater arm. I am confident that the basic principle is sound and, having made and tested 10-15 types of beater arm, that the beaters are the simplest possible. When fed with succulent crops it handles 4-6 tons an hour and takes 10-20 HP, but the rate of working falls and the power consumption rises with drier crops. Good grass goes through at 1 ton an hour and consumes 20 HP, grinding becomes more extravagant than this only with crops that are so dry and mature that protein extraction is unsatisfactory even in the laboratory.

In theory the amount of work that has to be done in grinding a mass of leaves is extremely small, so that in the earlier phases of this work there was always the hope that a much more efficient arrangement might be found. So far nothing has made it seem likely that this will prove possible and all the other arrangements consume more power. Tracey has carried out some (unpublished) experiments in which a weight was dropped on to 20 g. lots of grass and the percentage of protein liberated was measured after different amounts of work had been done. Satisfactory liberation required 6×10^9 ergs. If this could be replicated on a large scale, it would mean that a grinding rate of 1 ton per hour would take a little over 10 HP, which suggests that stamping mills would merit more thorough investigation than they have yet received.

In this connection it is interesting to consider what success animals have had in solving this problem. The bullock grinds grass with its teeth and tongue. Figures for its performance are somewhat approximate, but the ones given have been chosen so as to favour the efficiency of the bullock rather than the reverse. The jaw muscles of an 11 cwt. animal weigh 5 lb. and its tongue also weighs 5 lb. This weight is not all muscle used for chewing, but we will assume that it is and also that its rate of working is 0·01 HP per pound. This is the rate that Gray (1936) found for the strenuous conditions of dogs running on a treadmill and men rowing; it is, therefore, certainly a greater rate than would be compatible with the placid expression of a chewing bullock. We may be sure, therefore, that not more than 0·1 HP is being expended during 8 hours in which it collects grass and chews it roughly and the further 8 in which it chews the cud. After this the mass has about the consistency at which we aim for satisfactory protein extraction. The bullock eats 30 lb. dry matter or 150 lb. of fresh grass during the 16 hours, so that its 0·1 HP machinery is handling material at 9·4 lb. an hour. To get a rate of 1 ton per hour by replicating the same machinery we would need $2{,}240 \times 0{\cdot}1/9{\cdot}4 = 24$ HP. The actual rate of working may be only half this but it would seem that the course of evolution has not produced a mechanism much more efficient than our hasty adaptation.

The problem of pressing the juice from the ground leaf mass does not seem to be so nearly solved. On the laboratory scale it is easy, and on a large scale it is also easy if small molecules are the only valuable components of the extract. But much of the leaf protein

is present as particles up to 5μ in diameter and such particles are easily held back by tightly compacted masses of fibre. Arrangements that expose large bulks of material to high pressures are not therefore well adapted to our purpose. Moderate success has been achieved with a machine made at the National Institute for Agricultural Engineering. This has a perforated steel drum which is supported on three rollers inside it. Opposite each roller a larger wooden roller presses the drum on the outside, these outside rollers are driven and carry the drum around by friction. Ground leaves are fed on to the outside of the drum and are carried by it under each of the three wooden rollers in turn so that at each nip juice is pressed through the drum and into a tray inside. With this simple arrangement many tons of juice have been made but it is difficult to keep the layer of material on the drum even and the time during which pressure is applied in passage through the nips is too short for the juice to run away effectively.

Juice is so easily pressed by hand from minced leaves enclosed in a cloth and it is so easy, by continual hand pressing, to get a product containing only 65 per cent of water, that it is tempting to underestimate the problem of large-scale juice extraction. The pressure applied by hand is only about 30 lb. per sq. in., but it is maintained for many seconds, the charge is continually being rearranged, so that new parts are brought near the filtration surface by finger action. This is not an action that it would be easy to simulate with a machine, but it should not be needed if the thickness of the layer being pressed is kept small. With this in mind, new designs for a press are being discussed and in them three principles stand out clearly ; the layer, after pressing, should not be more than $\frac{1}{4}$ in. thick; pressure should be maintained for a few seconds ; there should be no movement between the charge under pressure and the filtration surfaces. There are so many ways of achieving these desiderata that we can be confident of success as soon as sustained work on the problem starts.

Any robust press designed to work quickly will allow some leaf fragments to pass through into the juice, so that a further stage of straining is needed before the protein can be separated. This presents no difficulties. The protein is then coagulated by heat or by adding acid. With many batches of juice, acid gives the better yield ; it also gives a purer product but one that is more difficult to handle because it is finely divided. If heat is applied rapidly with live steam, the curd is coarse and easily filtered off. From this stage on the protein is handled by normal chemical engineering methods. So far the substances remaining soluble in water after heating or acid coagulation have been discarded but, as is well known, the leaf at various stages in its growth contains valuable amounts of carbohydrate, and non-protein nitrogen part of which appear in this juice. It is therefore, essential that methods of using it should be explored.

By this sequence of grinding and pressing it is easy to get out in the form of protein a quarter of the nitrogen in leaves containing more than 2·6 per cent of nitrogen and possible, by rewetting the pressed mass and pressing again, to get out a third. The yield is lower than that reached in the laboratory but this is to be expected.

The remainder of the nitrogen is either soluble or else it remains as unextracted protein in the pressed residue. There would be obvious advantages in getting this out also; the question of how much it is economic to extract depends simply on the costs of extraction compared with those of growing more leaves. Further grinding is an obvious step but as already mentioned it has defects. We have made a fairly through study of the enzymic degradation of leaves (Holden, Pirie and Tracey 1950), mainly because of an interest in the liberation of viruses, but also with the application to protein extraction in mind. The enzymes used were juices or extracts from snails and various fungi; these would hardly be practical for large-scale use but the work showed that leaf residues were easily digested. In practice it would be easiest to seed the mass of leaf residue with a culture of a cellulase producing micro-organism and to let growth and fibre digestion proceed together. Hitherto cellulase has been an unreasonably neglected enzyme, but during the past few years it has begun to get the attention that its academic and practical interest warrants.

Protein which it is not economic to extract from the fibre will not, however be wasted. Cattle eat the residue readily, both when it is fresh and after drying, and it is very easy to ensile. The idea of drying it as winter feed is particularly attractive because although the nitrogen content is generally only 1·5 to 2 per cent, it is economical to dry and is satisfactorily handled by a rotary drier. Normal grass drying is not the unqualified success it was expected to be and one reason is that the protein content of a leaf is approximately proportional to its water content. The more worthwhile it is to make the dried product, therefore, the more water has to be dried off to get it. Thus really good leaves with 4·8 per cent of N on the dry matter may contain 93 per cent of water when cut, whereas those with only 2·4 per cent may contain only 75 per cent of water; to get a ton of dry matter from the former necessitates drying off 13 tons of water and from the latter 3 tons. The former is an extreme case; much of the dried "grass" at present being made in Britain is of the low quality of the latter. But if there were that extension in the use of fertilizers and irrigation water that is widely, and rightly, advocated, much more of the material coming to the driers would have such a high nitrogen and water content as to make drying doubtfully economic. Many proposals have been made for resolving the dilemma that the better the technique used in growing a forage crop the more expensive it becomes to dry it. To them we may add the proposal that the crop should first be processed to get out much of the protein and most of the water, so that only the residue containing about 65 per cent of water, would be dried. The proposal is that protein preparation should be a supplement to grass drying. It is easy to make a rough estimate of the protein and water content of a batch of leaves visually, and each load that arrives at a processing station should be sent straight to the drier if it is of low quality but should be used first for protein production if it is of high quality.

One of the difficulties encountered in the introduction of modern agricultural methods into undeveloped areas is the lack of power to run tractors and pumps. The residue of leaves from which protein has been extracted might be a valuable fuel. It could be used either

directly or after fermentation to give alcohol or methane ; the first course is simpler and more economical and the granular texture of the residue as it comes out of a press make it much more suitable for mechanical handling than the other agricultural wastes with which it is sometimes proposed that furnaces should be stoked. Research is already going on on the design of engines to run on low grade fuel ; it would seem that this is one of the fuels that should be tried.

The advantage of developing these techniques for separating protein from leaves depends on three propositions : That the leaf is the best place to look for further supplies of protein : That the protein and other components of the leaf are of more value to us after they have been separated from each other than they were when they were mixed : That there is no better method of making the separation. There will be little argument about the first, all the terrestrial protein sources now used on a large scale, e.g., beans, meat and milk depend on the leaf. Yeasts and some other micro-organisms can make protein directly from ammonium salts or even from atmospheric nitrogen and fish depend mainly on algæ and unicellular plants, but these sources should be looked on as complements rather than as alternatives to leaf protein. The only unusual feature of leaf protein separation is the intimacy with which the useful and the less useful parts are mixed in the starting material. In principle it is comparable to such well established separations as grain from chaff, oil from oil seeds and sugar beet tops and crowns from sugar beet. These separations are well known to be advantageous because by them the value of at least one of the products is enhanced. If leaves are to be used as a source of protein in the human diet, the only alternative would be to grow leaves with an exceptionally high protein content. Research on the conditions needed for a plant to produce high protein leaves regularly and a search for the species that can be easily made to do this would be both interesting and valuable, but for some time it is likely to be easier to grow a lower quality leaf and then to separate the digestible protein from the indigestible fibre. These are all issues that have been argued at greater length elsewhere (Pirie 1951, 1952, 1953).

Under existing conditions there are two main ways in which the separation is brought about. In the plant, the growth of seeds and tubers entails the translocation of protein, so that the fibre remains in the sere leaf and the protein appears in a digestible form along with fat and carbohydrate. Ruminant animals also separate the protein for us when they feed on leaves. Each process involves waste and the waste is especially great with animals because their value as sources of concentrated protein is a consequence of the fact that they are even more wasteful of carbohydrate than they are of protein. It is this fact that enables a bullock to lay down meat containing 60-70 per cent protein, in terms of dry matter, when fed on a diet containing only 10 per cent. Few will dispute that the products of animal conversion have more gustatory appeal than the products made from leaves are likely to have in the near future, but culinary enterprise can often bring about surprising changes. Furthermore a policy of leaf-protein production would probably not diminish the amount of food available for animals. First, there would be low-grade batches of protein suitable for pig and chicken

food ; second, there would be the leaf residue suitable for cattle food, and third, leaf protein production depends on the growing of high quality leaf. With leafy crops the improvements of quality by manuring, irrigation and frequent cutting would be accompanied by a total increase in yield both of protein and dry matter. This increase, it is true, could be achieved without the further step of making leaf protein, but the idea has never proved particularly attractive because such intensely cultivated crops tend to have too high a protein content for any but the most productive milking cows.

These advantages have naturally not escaped general notice and several commercial projects for making protein or protein concentrates have been started. Information about these projects is not always easily obtained but they seem to have the common defect that an attempt is made to get out the protein in one operation and to use one machine for all types of leaf. In practice the attempt does not succeed and the crop is passed several times through the same machine. Rollers and oil expellers or modifications of them are most commonly used. There seems to be no advantage in passing the charge through the same machine twice rather than passing it successively through two machines, or even three, each designed for the particular job to be done. *A priori* it is unlikely that a machine which is efficient at grinding leaves would also be efficient at separating the juice from the ground mass. All the evidence from our own work and the work of others suggests that it is better to start with an adjustable mill that can produce an approximately standard product from a wide range of raw materials, and then to feed this product into a press. Research is still needed until a workable unit has been built. This work can with advantage be done by anyone who knows the starting material, knows the aim, and has the enthusiasm to do it. The results will bear the same relationship to the final design that Trevethick's steam engines bear to those used now and the metamorphosis will call for the most expert available engineering skill, but some sort of working unit is a necessary first step.

Besides the work that is needed on the machinery there is also much scope for botanical and agricultural work. First there is the choice of crop. Hitherto a forage crop has had to have a texture and flavour acceptable to stock. A mill is less exacting and opens up wide botanical possibilities. Most of the necessary research to find which plants give the biggest return of dry matter and extractable protein per acre can be done on small scale plots. But once some conclusions have been reached they need confirmation by large-scale extraction, partly to confirm the laboratory results and partly to get enough protein to be sure that it has the expected feeding value. It may be that no crops better than those already in use, either in Britain or overseas, will be found at an early stage in the work but the standard crops offer much scope for variation. The effect of fertilizers and irrigation is already being actively studied at Rothamsted; this work could usefully be supplemented by a study of the extractability and quality of the protein. All the leafy agricultural wastes also need examination as do plants such as bracken and sedges that grow on uncultivated areas.

Work on the large-scale extraction of leaf protein has now been

going on in an uncertain manner with support from various Government departments for thirteen years. It seems to have got to a stage at which, with little more effort, a conclusion could be reached and machinery designed which would be suitable for use both in Britain and overseas.

Crook, E. M. (1946). The extraction of nitrogenous materials from green leaves. *Biochem. J.*, **40,** 197.

Crook, E. M. & Holden, M. (1948). Some factors affecting the extraction of nitrogenous materials from leaves of various species. *Biochem. J.*, **43,** 181.

Gray, J. (1936). Studies in animal locomotion. VI: The propulsive powers of the dolphin. *J. exp. Biol.*, **13,** 192.

Holden, M. & Tracey, M. V. (1948). The effect of fertilizers on the levels of nitrogen, phosphorus, protease and pectase in healthy tobacco leaves. *Biochem J.*, **43,** 147.

Holden, M. & Tracey, M. V. (1950). A study of enzymes that can break down tobacco-leaf components. 4. Mammalian pancreatic and salivary enzymes. *Biochem. J.*, **47,** 421.

Holden, M., Pirie, N. W. & Tracey, M. V. (1950). A study of enzymes that can break down tobacco-leaf components. 1. Digestive juice of Helix on leaf fibre. *Biochem. J.*, **47,** 399.

Pirie, N. W. (1942*a*). The direct use of leaf protein in human nutrition. *Chem. & Ind.*, **61,** 45.

Pirie, N. W. (1942*b*). Some practical aspects of leaf protein manufacture. *Food Manuf.* **17,** 283.

Pirie, N. W. (1950). The isolation from normal tobacco leaves of nucleoprotein with some similarity to plant viruses. *Biochem. J.*, **47,** 614.

Pirie, N. W. (1951). The circumvention of waste. (In: *Four Thousand Million Mouths.* Oxford University Press).

Pirie, N. W. (1952). Protein production from green leaves. *World Crops*, **4,** 374.

Pirie, N. W. (1953). The efficient use of sunlight for food production. *Chem. & E. Ind.*, 442.

Rouelle, H. M. (1773). Sur les fécules ou parties vertes des plantes, et sur la matière glutineuse ou végéto-animale. *J. de médecine, chirurgie, pharmacie* etc., **40,** 59.

Tracey, M. V. (1948). Leaf protease of tobacco and other plants. *Biochem. J.*, **42,** 281.

PUBLICATIONS

Physics Department

1. Schofield, R. K. (1952). Control of grassland irrigation based on weather data. *Proc. 6th Int. Grassland Congr.* (In the press.)

An examination of the physics of evaporation and the available experimental data leads to the conclusion that the evaporation of water from any land area covered by green vegetation cannot exceed a well-defined maximum however liberally the vegetation is watered.

This maximum evaporation depends on the weather and particularly on the amount of incident solar radiation, since this is the main source of the latent heat of vaporization.

Under effective irrigation, evaporation remains at or near the maximum and can be computed from weather data. Such computations together with measurements of rainfall provide a basis for the control of irrigation. The estimation of maximum evaporation could be issued to farmers by a Meteorological Service as is already done in England.

There are many details concerning the frequency of irrigation and equipment best suited to soil, crop and market conditions that will long remain topics for discussion and investigation, but in most cases the *quantity* of water needed can be closely estimated from weather data.

2. Penman, H. L. (1952). Experiments on irrigation of sugar beet. *J. agric. Sci.* **42,** 286-292.

It is assumed that maximum growth requires maximum transpiration, and that maximum transpiration can be maintained by keeping the soil near to field capacity throughout the growing season. Transpiration rates can be calculated from weather data (the basic principles are outlined and an example of the calculation given), and the paper describes four field experiments in which attempts were made to control the water content of the soil throughout the growing season, by irrigation from overhead spray-lines.

In spite of differences in season and soil, the four sets of data are consistent in showing that maximum sugar yield is obtained when the soil-moisture deficit (amount of rain or irrigation needed to restore the soil to field capacity) does not exceed about 2 in. in mid-July, or about 4 in. in mid-September.

3. Penman, H. L. (1953). The physical bases of irrigation control. *Proc. 13th Int. Hort. Congr. London,* 1952. (In the press.)

Irrigation designed to replace transpiration losses can be controlled if transpiration rates can be adequately estimated. As a particular form of natural evaporation, transpiration is dominantly a weather-controlled phenomenon in which plant character plays only a minor part, and rates can be calculated from weather data. The physical principles, involving energy supply and turbulent transport of vapour, are outlined for open water, first because they are most clearly revealed for open water, and second because for south east England it has been possible to convert estimated open water evaporation into estimated transpiration by using an empirical conversion factor. By an extension of the principles and the introduction of stomatal and daylength factors, it has proved possible to eliminate local factors and to estimate transpiration rate directly from weather data without first calculating the rate for a hypothetical open water surface. The special case of orchard crops is separately treated.

Field checks, chiefly in the more extreme climate of southern Australia, have been satisfactory, but only by accepting somewhat arbitrary values of stomatal conductance for diffusive flow of water vapour. The checks are equally successful for short crops and for orchard crops.

4. Penman, H. L. (1952). Contribution to discussion on " Relation between daily rainfall and flow of the River Shin." *Proc. Instn civ. Engrs, Part III,* 45–48.

5. Penman, H. L. (1953). Contribution to symposium on " Hydrology." *J. Instn Wat. Engrs.* (In the press.)

6. Long, I. F. (1951). Contribution to a symposium on " Electrical Meteorological Instruments." A recording anemometer. *J. Instn elect. Engrs*, **98**, 458.

A system of gears and cams converts the electrical impulses received from the anemometer (Mark III) into a continuous trace on a chart. Full scale deflection corresponds to a run-of-the-wind of fifty miles and the instrument then resets itself to zero.

Chemistry Department

7. Boyd, D. A., Cooke, G. W., Garner, H. V. & Moffatt, J. R. (1953). See No. 140.

8. Bremner, J. M. (1952). The nature of soil-nitrogen complexes. *J. Sci. Fd. Agric.* **3**, 497.

Results obtained at Rothamsted in recent work on soil-nitrogen complexes are discussed and information now available regarding the chemical nature of these complexes is reviewed. There is evidence that at least one-third, and some indication that as much as one-half, of soil nitrogen is in the form of protein. No method of separating this protein material from other soil constituents has been devised, but considerable information regarding its amino-acid composition is now available. There is evidence that some of the non-protein nitrogen of soil is in the form of nucleic acids and of amino sugars, but the chemical nature of much of this nitrogen remains obscure.

9. Cooke, G. W. (1952). Recent developments in fertilizer practice. *Bull. Docum. Ass. int. Fabr. Superph.* Paris, **12**, 20.

A summary in French and English of results of recent field experiments.

10. Cooke, G. W. (1952). Försök i England rörande sådd av handelsgödselmedel. *Växt-närings-Nytt.* **8**, 28.

A summary in Swedish of results of recent field experiments on fertilizer placement.

11. Crowther, E. M. & (Walker, T. W.) (1952). The relative values of alternative liming materials. *Agriculture, Lond.*, **59**, 251.

The results of a number of field experiments carried out by advisory soil chemists from 1944 to 1948 are summarised. In most of the experiments the standard rate of application was determined by the Hutchinson-McLennan " lime-requirement method." Burnt lime was tested at half and full standard rate and the other materials generally at the standard rate. On the average, the standard rates doubled the crop yields, but applications at half this rate increased yields by about 85 per cent. Little is to be gained therefore under normal conditions from liming at higher rates than are indicated by laboratory tests, and it will often prove more economic to use even smaller dressings and to repeat them after a few years when further tests show this to be advisable. Ground limestones, ground to give about 40 per cent through the 100 mesh sieve, were fully as effective as equivalent amounts of burnt lime, presumably because they can be spread and incorporated into the soil more evenly than burnt limes. Magnesian limes and limestones had some advantage over high-calcium materials in a few experiments on recently reclaimed light land, and gave similar results on more normal soils.

12 Crowther, E. M. (1952). American fertiliser practice and problems. *Fertiliser Soc. Trans.* (*Proc. No.* 17).

This paper summarises American research on soil fertility and fertilizer problems, as seen during an eleven-week tour with the assistance of the Economic Co-operation Administration. An attempt was made to assess the relevance for British conditions of a number of recent American developments in the production and use of fertilizers and to understand the geographical, historical and technical reasons for the differences in practice between roughly comparable parts of the two countries. Special attention was given to the use of ammonium nitrate as such, the injection of anhydrous ammonia, the ammoniation of mixed fertilizers, the production of phosphorus fertilizers by high-temperature processes, the use of ground phosphate rock in Illinois and adjoining States but not elsewhere, the ammonium citrate

test for " available phosphoric acid " in fertilizers, the methods adopted for fertilizer control and for compiling statistics for local fertilizer consumption, methods of fertilizer placement, the use of rapid soil tests for advisory work on manuring, recent work on radio-phosphorus.

13 CROWTHER, E. M. (1953). The sceptical soil chemist. *J. Soil. Sci.* **4**, 107.

In a presidential address to the British Society of Soil Science, delivered at the Summer Meeting held at the Royal Agricultural College, Cirencester, an attempt was made to review some aspects of the tactics and strategy in soil research. Quotations from Plato on denudation and soil erosion and from Robert Boyle and John Evelyn on investigating problems of crop nutrition and manuring by surveys and experiments were used to show how far brilliant pioneers could go in interpretive descriptions and in formulating research projects. The early promise was checked by the lack of appropriate techniques and special funds for making reliable agricultural experiments and surveys, as well as by the inadequacy of the more basic sciences. Somewhat similar conditions still remain, especially in under-developed areas, and it is important to ensure that field experiments and soil surveys keep pace with laboratory investigation on soils.

Some American attempts to build up comprehensive systems for treating all kinds of soil in a manifold classification based on a set of differentiating characteristics are criticised. An alternative treatment might be to recognize the practical value of many alternative and overlapping groups of similar or geographically associated kinds of soil and then to endeavour to relate each of these groups to their environmental conditions, using rigid statistical methods, whenever possible. If the problem of correlating internal and external characteristics of the units of landscape having similar soils were regarded as an attempt to fit the distributions of related soils into a hyper-space model of environmental and historical conditions, some of the past controversies about certain higher categories in soil classification would be seen to represent projections on to different planes in the model. It would also be clear that where a single kind of soil occurs in regions differing markedly in one soil-forming factor, there must of necessity be concomitant variations in some other compensating factor. The analogy with a hyper-space model and the systematic search for relationships between soil and environmental conditions may prove more profitable than attempts to devise complete formal schemes for soil classification based on groupings by single factors.

14 CROWTHER, E. M. (REYNOLDS, J. R. & SHORROCK, R. W.) (1952). Experiments on the manuring of peas. *Agriculture, Lond.* **58**, 584.

N, P and K fertilizers broadcast in preparing seedbeds for threshed peas gave only small responses on the average of a number of field experiments on commercial farms. The only consistent result was a gain from potassium fertilizers on soils found by soil analysis to be deficient in this element. Another series of experiments by G. W. Cooke, reviewed in the Rothamsted Report for 1951 (p. 37), also showed low responses from broadcasting PK fertilizers for peas, but much better results were obtained by placing the fertilizer in a band to the side of and below the seed.

15. CROWTHER, E. M. & BENZIAN, B. Committee on nutrition problems in forest nurseries. Summary Report on 1950 experiments. *For. Comm. Rept. on For. Res.* 1950-51, 113.

Annual report on investigations reviewed in the Rothamsted Report for 1950, 41–43.

Pedology Department

16 BLOOMFIELD, C. (1952). The distribution of iron and aluminium oxides in gley soils. *J. Soil Sci.*, **3**, 167.

An account of an investigation of the distribution of ferric and aluminium oxides in two gley soils from Lancashire of different types. In a mottled gley soil, it was found that the distribution of free aluminium oxide was the same as that of the ferric oxide, i.e. the aluminium was concentrated in the iron-stained zones. Despite differences in the intensity of gleying, the free iron of the grey (bleached) soil was constant. For an unmottled gley soil

under peat, the results indicated removal of the sesquioxides in a vertical direction.

17 Brown, G. & Greene-Kelly, R. (1952). Diffraction by randomly inter-stratified layers in a clay mineral. *Brit. J. appl. Phys.*, **3**, 281.

The Hendricks-Teller theory of diffraction by randomly interstratified minerals has been applied to the Li-montmorillonite-glycerol system and agreement between calculated and observed results is good.

18 Brown, G. & Norrish, K. (1952). Hydrous micas. *Miner. Mag.*, **24**, 929-932.

Calculation of structural formulae of hydrous micas based on the assumptions that the excess of water is present as interlayer oxonium ions replacing potassium of the ideal mica give structural formulae which are in good agreement with the formulae of ideal micas.

19 Brown, G. Norrish, K. & Greene-Kelly, R. (1952). Organic derivatives of montmorillonite. *Clay Min. Bull.*, **1**, 214-220.

Chemical and X-ray diffraction studies of alleged organic derivatives of montmorillonite failed to confirm their existence.

20. Butler, J. R. & Le Riche, H. H. (1951). *Spectrochim. Acta*, **4**, 435-438.

A spectrographic modification of the internal standard method.

21. Greene-Kelly, R. (1952). Organic derivatives of montmorillonite. *Nature, Lond.*, **169**, 756.

(1952). Organic derivatives of montmorillonite. *Clay Min. Bull.*, **1**, 214.

In conjunction with G. Brown and K. Norrish the evidence in favour of the formation of covalent bonded groups to montmorillonite is critically examined. As a result of the study of derivatives prepared by Deuel and by the authors, they concluded that covalent bonded groups are not formed.

22. Greene-Kelly, R. (1952). Irreversible dehydration in montmorillonite. *Clay Min. Bull.*, **1**, 221.

The occurrence of irreversible collapse of the sheets of montmorillonite on moderate heating is found to depend in the nature of the interlayer ion. In particular the lithium ion is found to be very effective. This result is discussed in terms of the Mering hypothesis that irreversible collapse is accompanied by loss of structural water. It is concluded that this hypothesis is not likely to hold for this type of irreversible behaviour.

23. Greene-Kelly, R. (1952). A test for montmorillonite. *Nature, Lond.*, **170**, 1130.

24. Brindley, G. W. & MacEwan, D. M. C. (1952). Structural aspects of the mineralogy of clays and related silicates. *J. Brit. Cer. Soc.*, Anniversary Volume. (In the press.)

A detailed account of the structural features of layer silicates, and an attempt to correlate them with chemical composition, morphology and cation exchange properties.

25. MacEwan, D. M. C. (1953). Randomly stacked layers in clay minerals. *Nature, Lond.* **171**, 616.

If the X-ray diffraction from the basal planes can be separated from the rest of the diffraction given by a clay mineral, then the cosine transform of $i = \left\{ I(\mu) \Big/ \Theta |F_l|^2 \right\} 1$ (the notation being as in James, *Optical Principles of the Diffraction of X-rays* and F_1 being the scattering factor of a *layer*) gives the number of layers at an arbitrary distance from any given layer, on the assumption that only one type of mineral layer is present, and that the interlamellar material (commonly water) has a low scattering power for X-rays. This function is difficult to calculate in practice, and it is shown that the related function

$$\Sigma_l \frac{I_r}{\Theta |F_l|^2} \cos 2\pi\mu_r R$$

where I_γ is the integrated intensity of an X-ray line and μ_γ its reciprocal spacing, very often gives essentially the same information. This function is readily calculable.

26. MacEwan, D. M. C. (1952). The First National Conference on Clays and Clay Technology at Berkeley, California. *Claycraft.* **26**, 204
An account.

27. Stephen, I. (1952). A study of rock weathering with reference to the soils of the Malvern Hills. Part I. Weathering of biotite and granite. *J. Soil Sci.*, **3**, 20.

28. Stephen, I. (1952). A study of rock weathering with reference to the soils of the Malvern Hills. Part II. Weathering of appinite and 'Ive-Scar rock.' *J. Soil Sci.*, **3**, 219.
A study of four residual soils derived from different members of the Malvern crystalline-complex has shown the importance of the parent bedrock in determining their mineralogical composition. The coarser material in the soils consists mainly of the relatively unweathered minerals characteristic of the underlying rock, whilst the composition of the colloidal material reflects the trend of alteration of the primary minerals on weathering. The colloids of the soils derived from the untrabasic biotite- and hornblende-rich rocks consist mainly of chlorite-vermiculite. The progressive change from chlorite in the weathered rock to mixed chlorite-vermiculite and vermiculite in the soil has been traced. It is suggested that the mechanism of the change may be successive exchange of $2H^+$ for Mg^{2+} leading to conversion of OH^- into H_2O and results finally in the disintegration of the brucite layer leading to esparate exchangeable ions as in vermiculite. With increase in the feldspar content of the bedrock (diorite), illite in addition becomes prominent in the soil colloids, and is dominant in those derived from granite.

Soil Microbiology Department

29. Meiklejohn, J. (1953). Iron and the nitrifying bacteria. *J. gen. Microbiol.* (In the press.)
The oxidation of ammonia to nitrite in enrichment cultures of *Nitrosomonas spp.* was hastened by 6 mg. Fe/1 in the medium. Manganese did not replace iron as a stimulant; it was toxic. *Nitrosomonas europaea* (Jensen's strain) and a strain of *Nitrobacter winogradskii*, had in pure culture, very small absolute requirements for iron; they oxidised ammonia and nitrite respectively in media purified with 8-hydroxyquinoline, and with no iron added. Small amounts of iron hastened the oxidation of ammonia and nitrite; the minimum concentration giving this stimulating effect was 0·1 mg. Fe/1 for the strain of *Nitrosomonas europaea* and 0·3 mg. Fe/1 for the strain of *Nitrobacter winogradskii.* The optimum amount of iron for oxidation appeared to be about 6 mg./1 for both species. Both species tolerated 112mg. Fe/1 (about 0·002 M), but oxidation was delayed, markedly in the case of *Nitrobacter winogradskii*, by 560 mg./1 (about 0·01 M).

30. Meiklejohn, J. (1953). Some organic substances and the nitrifying bacteria. *Proc. Soc. appl. Bact.* (In the press.)
1. The rate of nitrification in mixed cultures is not affected by the simultaneous decomposition of cellulose.
2. No stimulation of the rate of nitrification was observed in cultures containing: culture filtrates, soil extract, thiamin, yeast extract, urine, or *beta*-indoleacetic acid. These substances either had no effect, or in larger doses, delayed or stopped nitrification.
3. Peptone is toxic to the nitrifying bacteria.
4. Potassium chlorate does not affect the oxidation of ammonia to nitrite, but it stops the oxidation of nitrite to nitrate in cultures, as it does in soil.
5. M/25 sodium fluoride stops the oxidation of ammonia to nitrite.

31. Meiklejohn, J. (1952). Minimum phosphate and magnesium requirements of nitrifying bacteria. *Nature, Lond.* (In the
A strain of *Nitrosomonas europaea* survived eleven successive transfers on to medium with phosphate omitted. A strain of *Nitrobacter winogradskii*

ceased to oxidise nitrite to nitrate in the second transfer o phosphate-deficient medium but the bacteria survived. Both species continued to oxidise ammonia or nitrite respectively up to the fourth successive transfer on to medium with magnesium omitted.

32. Meiklejohn, J. (1953). The nitrifying bacteria: A review. *J. Soil Sci.* (In the press.)

33. Mollison, J. E. (1953). Effect of partial sterilization and acidification of soil on the fungal population. *Trans. Brit. mycol. Soc.* (In the press.)

The effects on the soil fungal population of steam, formalin and acid treatments applied to an old forest nursery soil over Lower Greensand at Ampthill, Bedfordshire are reported. Samples of soil from the different plots were taken at intervals up to 25 months after treatment and the numbers of fungi per gram of soil estimated by plating dilutions. Steaming reduced the total numbers of fungi throughout the period tested. The fungi re-colonizing steamed plots were varied. Formalin also reduced numbers but the recolonizing species were dominated by *Trichoderma*. The numbers of fungi increased slightly after acid treatment.

34. Nutman, P. S. (1953). Studies on the physiology of nodulation formation. IV. The mutual inhibitory effects on nodule production of plants grown in association. *Ann. Bot. N.S.* (In the press.)

The number of root nodules formed on a clover plant in test tube culture on agar varies directly with volume of medium and inversely with number of plants present. The inhibitory activities of the following selected lines of clover are compared: effective in N-fixation and ineffective, sparsely and abundantly nodulating, resistant to infection by *Rhizobium* and normally susceptible, and plants which nodulate early or late in seedling growth. Early lines of plant inhibit nodulation more strongly than late lines but no differences show in the inhibiting activities of any of the other categories of plant, in spite of large differences in plant size. Successive replanting of agar cultures also leads to inhibition. Non-leguminous companion plants (lettuce and flax) are less inhibitory for clover nodulation than a second clover plant.

Nodulation of lucerne and vetch are similarly affected by the presence of a companion plant of the same species but among heterogeneous associations of different species, inhibition is not invariable. Inhibition is not related to the numbers of bacteria of either of the strains present or to the pH of the medium. The hypothesis is advanced that inhibition may be due to the secretion of specific inhibitory substances from the root.

35. Singh, B. N. (1952). Nuclear division in nine species of small free-living amoebae and its bearing on the classification of the order Amoebida. *Phil. Trans. B.*, **236,** 405-461.

A study of nine species of small free-living amoebae has been made under standardized and reproducible cultural conditions, by a new method than enables specimens in all stages of division to be obtained easily. In all species the resting nucleus shows a Feulgen-negative nucleolus and Feulgen-positive chromatin granules. Nuclear division in these species and in other amoebae described by other workers is of two main types on which it is proposed to create two new families—Schizopyrenidae and Hartmannellidae. In Schizopyrenidae, the type genus Schizopyrenus n.g. and two other genera, Naegleria and Didascalus n.g., are defined. *Naegleria gruberi, Didascalus thorntoni* n.sp., *Schizopyrenus russelli* n.sp., *S. erythaenusa* n.sp. and *S. atupus* n.sp. are described. In Hartmannellidae the type genus Hartmannella is defined. *H. glebae, H. rhysodes* n.sp., *H. leptocnemus* n.sp. and *H. agricola* are described. The relation of the proposed classification to previously defined families and general of amoebae, and its bearing on phylogeny are discussed.

36. Singh, B. N. (1953). The effect of partial sterilization by steam and formalin on the numbers of amoebae in field soil. *J. gen. Microbiol.* (In the press.)

In Sitka spruce nursery plots the numbers of amoebae in steam treated soil rose with the increase in the bacterial population. The population of

amoebae over a period of seven months was much higher in this soil than in the untreated or the formalin-treated soils. The formalin-treated soil had significantly lower numbers of amoebae compared with the untreated soil over a period of one year, although the bacterial numbers were often higher in the former than in the latter. it is suggested that the unsuitable quality of bacterial food supply might be responsible for keeping the numbers of amoebae in check in the foramlin-treated soil. Double formalin treatment seemed to suppress further the numbers of amoebae.

37. THORNTON, H. G. (1952). The symbiosis between *Rhizobium* and leguminous plants and the influence on this of the bacterial strain. *Proc. roy. Soc. B.*, **139,** 170.

38. NUTMAN, P. S. (1952). Host factors influencing infection and nodule development in leguminous plants. *Proc. Roy. Soc. B.* **139,** 176.

These two papers formed part of a Symposium held at the Royal Society and were reviews of recent work on the symbiosis between *Rhizobium* and its host legume.

39. WALKER, N. & WILTSHIRE, G. H. (1953). The breakdown of naphthalene by a soil bacterium. *J. gen. Microbiol.*, **8.** (In the press.)

A bacterium isolated from soil can be grown with naphthalene as sole carbon source and produces *D-trans*-1:2-dihydro-1:2-dihydroxynaphthalene and salicylic acid.

40. WALKER, N. & (EVANS, W. C.) (1952). Pathways in the metabolism of the mono-hydroxybenzoic acids by soil bacteria. *Biochem. J.*, **52.** (In the press.)

Several strains of *Ps. fluorescens* have been found to grow in a mineral salt medium and using either salicylic acid or *m*-hydroxybenzoic acid as the sole carbon source. Salicylate grown cells are adapted simultaneously to catechol and *cis-cis*-muconic acid but not to phenol or any of the possible dihydroxybenzoic acids.

Cells grown on *m*-hydroxybenzoic acid are simultaneously adapted to gentistic acid. Thus, salicylic acid is metabolised through catechol and *m*-hydroxybenzoic acid via gentisic acid.

Botany Department

41. WATSON, D. J. (1952). The physiological basis of variation in yield. *Advanc. Agron.*, **4,** 101.

A review of work on the physiological analysis of plant growth and yield, with special reference to the nature and causes of variation in net assimilation rate and leaf area of field crops.

42. WATSON, D. J. & WATSON, M. A. (1953). Comparative physiological studies on the growth of field crops III. The effect of infection with beet yellows and beet mosaic viruses on the growth and yield of the sugar beet root crop. *Ann. appl. Biol.* **40,**1.

Infection with beet yellows virus depressed the dry matter yield of sugar beet plants by decreasing both net assimilation rate (NAR) and leaf area. It did not reduce leaf number.

Plants infected at the end of June had 30-50 per cent of their leaf area yellowed from mid-August. Later infection caused less yellowing. The yellowing almost sufficed to account for the decrease in NAR, if yellowed parts of leaves do not photosynthesise. However, there is evidence that the rate of photosynthesis may not be much slowed by infection; if so the decrease in NAR indicates a large increase in respiration rate.

The effects of yellows-infection on leaf area and NAR were independent, e.g. late-sown plants suffered a greater reduction of leaf area but a smaller reduction of NAR than early-sown plants.

Most of the loss of dry matter was in the root; the dry weight of petioles (including stem tissue) was also decreased, but the dry weight of leaf lamina was little affected.

Yellows-infection increased the carbohydrate content, especially reducing sugars, and decreased the water and nitrogen contents of the leaf lamina. It increased the nitrogen content of petiole and root but did not change their water content. It reduced the sugar content of the root, but the loss of sugar yield was mainly attributable to decreased root weight.

Infection with beet mosaic virus caused a smaller loss of yield than yellows-infection; the dry weights of all parts of the plant were decreased. Mosaic-infection reduced both NAR and leaf area. It had no effect on carbohydrate content or water content of the leaf lamina, or on the water content of petiole and root. It increased the nitrogen content of all parts of plants that received no nitrogenous fertilizer, but not of nitrogen-treated plants. It slightly increased the sugar content of the root.

Biochemistry Department

General Papers

43. Mann, P. J. G. (1951). Review of work on manganese oxidation in higher plants. *Rep. Rothamsted exp. Sta.*, **1951,** 168.

44. Pirie, N. W. (1952). Agriculture : The universal provider. *Chem. Ind.*, 473.

45. Pirie, N. W. (1952). On Scientific reviewing and writing. *Science,* **116,** 401.

46. Pirie, N. W. (1952). The biochemistry of conception control. *Eugen. Rev.*, **44,** 129.

47. Pirie, N. W. (1952). The effects of size and stability on antigenicity. *Symp. biochem. Soc.*, **10,** 81.

48. Pirie, N. W. (1952). Geochemical aspects of the origin of complex molecules on the earth, as precursors to organic life. (by V. M. Goldschmidt. Edited by N.W.P.). *New Biol.*, **12,** 97.

48a. Pirie, N. W. (1952). Vital blarney. (Review of *The physical basis of life* by J. D. Bernal). *New Biol.*, **12,** 106.

49. *See* 64.

50. Tracey, M. V. (1953). Principles of biochemistry: a biological approach. London : Isaac Pitman. (In the press.)

Research Papers

51. (Boyland, E., Manson, D., Solomon, J. B.) & Wiltshire, G. H. (1953). The occurrence of *m*-hydroxybenzoic acid in urine. *Biochem, J.*, **53,** 420.

3-hydroxybenzoic acid was isolated from the urine of rats and rabbits fed on a normal diet and was increased by dosing with naphthalene.

52. (Boyland, E.) & Wiltshire, G. H. (1953). Metabolism of naphthalene by liver slices. *Biochem. J.*, **53,** 424.

Naphthalene was oxidised to 1:2-dihydro-1:2dihydroxynaphthalene by liver slices from rats and rabbits.

53. Holden, M. & Pirie, N. W. (1952). The behaviour of nucleic acids in tobacco leaf. *Proc. Second Int. Congr. Biochem.*, 259.

54. Kenten, R. H. & Mann, P. J. G. (1952). Hydrogen peroxide formation in oxidations catalysed by plant a-hydroxyacid oxidase. *Biochem. J.*, **52,** 130.

1. Hydrogen peroxide is produced during the oxidation of lactate, glycollate and glyoxylate catalysed by plant α-hydroxyacid oxidase. This has been shown by the effect of catalase on the oxygen uptake.

2. The oxidation products depend on the amount of catalase present. In the absence of catalase the enzyme-catalysed reactions are followed by non-enzymic reactions between the hydrogen peroxide and pyruvate or glyoxylate, with the formation of acetate or formate respectively.

3. It is suggested that oxalate is the product of the enzyme-catalysed oxidation of glyoxylate.

55. Kenten, R. H. & Mann, P. J. G. (1952). The oxidation of manganese by enzyme systems. *Biochem. J.*, **52**, 125.

1. The oxidation of bivalent manganese (Mn++) can be brought about by enzyme systems producing hydrogen peroxide such as D-amino-acid oxidase, xanthine oxidase and plant amine oxidase systems coupled with peroxidase systems.

2. With high Mn++ concentrations the oxidation was demonstrated by the increased oxygen uptake and by the estimation of manganese oxidation product with hydrazine. The oxidation product accumulates in both pyrophosphate and orthophosphate media.

3. With low Mn++ concentrations the oxidation was demonstrated by the increased oxygen uptake of the system in the presence of oxalic acid. Under these conditions the manganese is involved in a cycle of oxidation and reduction.

4. The oxidation of Mn++ by peroxidase systems can be used as a test for hydrogen peroxide. By this test it has been shown that plant α-hydroxy-acid oxidase produces hydrogen peroxide while catalysing the oxidation of L-lactic and glycollic acids.

56. Pirie, N. W. (1952). Protein production from green leaves. *World Crops*, **4**, 374.

A brief description of the equipment used to extract protein from field crops on a large scale and some information about efficiency of extraction and the quality of the product.

57. Smithies, W. R. (1953). Determination of glucosamine in the presence of interfering substances. *Biochem. J.* (In the press.)

Glucosamine on acetylation with acetic anhydride and anhydrous sodium acetate forms N-acetyl glucosamine in quantitative yield. This may be determined by the Morgan and Elson method without interference from amino acids and sugars.

58. Tracey, M. V. (1952). Chitinase and cellulase of nematodes. *Proc. Second Int. Congr. Biochem.*, 242.

59. Tracey, M. V. (1952). The determination of glucosamine by alkaline decomposition. *Biochem. J.*, **52**, 265.

1. A method for the estimation of amino sugars in the range 50-500μg., by alkaline decomposition and estimation of the ammonia produced, is described.

2. Elimination of interference by other nitrogen containing compounds is discussed.

Plant Pathology Department

General Papers

60. Bawden, F. C. (1952). Reducing losses from virus diseases. *Gdng. ill.*

61. Bawden, F. C. (1953). Criticism of binomial nomenclature as applied to plant viruses. In *Virus and Rickettsiae Classification and Nomenclature. Ann. N.Y. Acad. Sci.* **56**, 538.

62. Bawden, F. C. (1952). The control of plant diseases. *Listener*, **48**, 294.

63. Bawden, F. C. (1953). Controlling plant diseases. *Agriculture, Lond.*, **59**, 451.

64. Bawden, F. C. & Pirie, N. W. (1953). Virus multiplication considered as a form of protein synthesis. (In: *Multiplication of Viruses.* Oxford University Press. p. 21.)

65. Broadbent, L. (1952). Transmission of potato viruses by aphids and spread in the field. *Proc. Conf. Potato Virus Diseases, Wageningen-Lisse*, 9.

66. Broadbent, L. (1952). The control of potato virus diseases by application of insecticides. *Proc. Conf. Potato Virus Diseases, Wageningen-Lisse*, 23.

67. Broadbent, L. (1952). The control of potato virus diseases by roguing and early harvesting. *Proc. Conf. Potato Virus Diseases, Wageningen-Lisse*, 34.

68. Broadbent, L. (1952). Barrier crops may help to reduce cauliflower mosaic. *Grower*, **38**, 1140.

69. Glynne, M. D. (1952). Observations on chocolate spot. *In:* The Rothamsted experiments on field beans, Part 2. *J. R. agric. Soc.* (In the press.) **113**, 70.

70. Gregory, P. H. (1952). The sycamore sooty bark fungus (*Cryptostroma corticale*). *Essex Nat.*, **29**, 13.

71. Gregory, P. H. (1952). Presidential Address. Fungus spores. *Trans. Brit. mycol. Soc.*, **35**, 1.

72. Hull, R. (1952). Can Virus Yellows be avoided in 1952 ? *Brit. Fmr.*, No. 44, Feb. 29.

73. Hull, R. (1952). The Virus Yellows war is not yet won. *Brit. Sug. Beet Rev.*, **21**, 29.

74. Hull, R. The control of Virus Yellows in sugar beet seed crops. *J. R. agric. Soc.* **113**, 86.

75. Kassanis, B. (1951). The control of plant viruses by therapeutic methods. *Proc. Conf. Potato Virus Diseases, Wageningen-Lisse*, 13.

Research Papers

76. Bawden, F. C. & (Freeman, G. G.) (1952).The nature and behaviour of inhibitors of plant viruses produced by *Trichothecium roseum* Link. *J. gen. Microbiol.*, **7**, 154.

Culture filtrates of *Trichothecium roseum* contain two heat-stable substances that inhibit infection with plant viruses. One is trichothecin, an anti-fungal substance with the molecular formula $C_{19}H_{24}O_5$; it sometimes visibly damages bean leaves. The other was isolated as a polysaccharide, $[\alpha]_D^{19°} = -33°$; it contains 1·1-1·4% nitrogen, yields 60-70% reducing sugars (as glucose) on acidic hydrolysis, and the predominant (45%) component sugar is D-galactose. The polysaccharide does not combine with tobacco mosaic virus *in vitro*.

The extent to which infection is inhibited depends on the species of the host plant but not on the identity of the virus. Trichothecin, like ribonuclease, is relatively more effective with beans than with *Nicotiana glutinosa*, whereas the polysaccharide and two derivatives of trichothecin (trichothecolone and acetyl-trichothecolone) affect *N. glutinosa* more than beans. Trichothecin inhibits infection when sprayed over leaves a day after they have been inoculated with viruses, but is ineffective when applied 2 days before. The polysaccharide inhibits when sprayed over leaves before inoculation but not after. It is suggested that inhibitors act by temporarily altering the metabolism of leaf cells so that introduced virus particles cannot multiply and are inactivated.

77. Bawden, F. C. & Kleczkowski, A. (1953). The behaviour of some plant viruses after exposure to ultraviolet radiation. *J. gen. Microbiol.*, **8**, 145.

Preparations of tobacco mosaic virus (TMV) inactivated by ultraviolet radiation interfered slightly with infection by active tomato bushy stunt (BSV) and Rothamsted tobacco necrosis (RTNV) viruses, and much more so with active TMV. Similarly, inactivated RTNV interfered slightly with infection by TMV and more so with active RTNV. In contrast, inactivated BSV did not affect the numbers of lesions produced by active virus preparations.

The residual infectivity of irradiated preparations of RTNV and BSV was greater when inoculated plants were exposed to light than when they were kept in the dark. This occurs because of some light-sensitive mechanism in the host cells and exposing the irradiated virus preparations to visible light did not affect their infectivity. Irradiated preparations of TMV had the same residual infectivity whether plants were placed in the light or dark after inoculation.

Although the three viruses have particles of different sizes and shapes, the course of inactivation by ultraviolet with each approximated closely to that of a first order reaction.

78. Broadbent, L., Gregory, P. H. & Tinsley, T. W. (1952). The influence of planting date and manuring on the incidence of virus diseases in potato crops. *Ann. appl. Biol.*, **39**, 509.

Field experiments with Majestic potatoes were made over six years at Rothamsted to test the effects of varying date of planting and manuring on the yield of tubers and the incidence of the aphid-transmitted leaf roll and Y (rugose mosaic) viruses. Yield was increased by early planting, and by all the manures, especially dung. Early planting also usually increased the incidence of virus diseases. Different manures had different effects on disease incidence; the average results from all comparisons showed the largest increase in incidence of both viruses from the use of dung; sulphate of ammonia increased the incidence of leaf roll, and muriate of potash that of rugose mosaic. Counts in two years showed that aphid populations were highest on the earlier planted potatoes, and were increased by dung, sulphate of ammonia and superphosphate, but were reduced by muriate of potash.

79. Glynne, M. D. (1953). Production of spores by *Cercosporella herpotrichoides*. *Trans. Brit. mycol. Soc.*, **36**, 46.

Eyespot lesions on young wheat plants in the field regularly produced conidia of *Cercosporella herpotrichoides* Fron. in early spring. Conidia were not produced on mature growing plants, but, after ploughing, lesions on infected straws spored freely, especially in wet weather.

In the laboratory, eyespot lesions on straws produced spores when soaked in water for 24 hours, drained and kept continuously wet. Five mm. discs, cut from cultures on potato dextrose or water agar, produced spores abundantly when kept touching water at favourable temperatures, but excess water reduced sporing. Spores developed most abundantly when temperatures fluctuated between −3 and 13° C, were produced freely when temperatures fluctuated between 12 and 22°C, more slowly at 1–2°C and were not produced at 24–25°C. Daylight did not seem to influence spore production.

80. Gregory, P. H. & Hirst, J. M. (1952). Possible role of basidiospores as air-borne allergens. *Nature, Lond.*, **170**, 414.

Routine observations with the automatic volumetric suction trap in the open air at Rothamsted revealed the occurrence of transient clouds of hyaline basidiospores. The numbers of coloured basidiospores were reasonably uniform between mid-August and mid-September and seldom fell below 1,000 per cubic metre. It is suggested that these concentrations of basidiospores may have significance as respiratory allergens. Older trapping methods had failed to reveal the basidiospore content of the air.

81. Gregory, P. H. (1952). Spore content of the atmosphere near the ground. *Nature, Lond.*, **170**, 475.

Knowledge of the composition and variation of the air ' spora ' is important in agriculture and in medicine. Methods in current use have various defects, particularly in failing to catch the smaller spores at all and giving a logarithmic bias in favour of the larger types. The Cascade Impactor has been used in sampling the outdoor air ' spora ' at Rothamsted during a number of 24-hour periods, and the spores in the four size fractions obtained with this trap at different times of day and night are described. Some components of the air ' spora ' cannot yet be classified even to a major group of organisms. The Cascade Impactor allows a preliminary visual examination of the entire air ' spora ', and in comparative tests it was found that the Hirst automatic volumetric suction trap was, in practice, equally efficient.

82. Hull, R. & Gates, L. F. (1953). Experiments on the control of beet yellows virus in sugar beet seed crops by insecticidal sprays. *Ann. appl. Biol.*, **40**, 60.

Field experiments made in eastern England between 1943 and 1951 showed that *Myzus persicae* lived on stecklings throughout some winters and that most of the yellows in transplanted seed crops were plants that became infected in the steckling bed. A larger proportion of stecklings sown at the end of July or early August became infected than of those sown about a month later. The incidence of yellows was reduced by spraying stecklings with nicotine in late autumn after aphids had ceased migrating. A greater reduction was obtained with persistent and systemic organo-phosphorus insecticides; in one experiment three applications of E.605 reduced incidence to one-ninth that in unsprayed plots. However, in years when stecklings were exposed to very many incoming aphids, plots sprayed three times had 78 per cent of the plants with yellows. Although spraying often greatly reduces the incidence of yellows, it is unlikely to give adequate control in years and districts in which many viruliferous aphids move in the autumn. Spraying in September and October is usually more effective than in August.

83. Kassanis, B. (1952). Some effects of high temperature on the susceptibility of plants to infection with viruses. *Ann. appl. Biol.*, **39**, 358.

When plants were kept at 36° C for some time before inoculation, their susceptibility to infection by five mechanically transmissible viruses was greatly increased. When kept at 36° after inoculation, fewer local lesions were produced than at lower temperatures, but the effects of the post-inoculation treatment differed with different viruses. Tomato spotted wilt and tobacco mosaic viruses multiply in plants at 36°, and the post-inoculation treatment reduced the local lesions they caused to numbers that varied between 10 and 90 per cent of the control; these two viruses also have large thermal coefficients of heat inactivation. By contrast, tobacco necrosis, tomato bushy stunt and cucumber mosaic viruses, were much affected by post-inoculation treatment, lesion formation being completely prevented by exposure to 36° for a day or more. These three viruses appear not to multiply in plants at 36°, and although they have high thermal inactivation points, they have small temperature coefficients of thermal inactivation.

The extent to which lesion formation was affected by pre- or post-inoculation exposure of plants to 36° depended not only on the length of treatment, but also on the physiological condition of the plants.

The symptoms of infected plants changed considerably if kept at 36°. At 36° *Nicotiana glutinosa*, inoculated with tobacco mosaic virus, gave chlorotic local lesions instead of necrotic ones, and became systemically infected. When systemically infected plants were brought to ordinary glasshouse temperature, the infected tissues all collapsed and died in a day.

84. Kleczkowski, A. (1953). A method for testing results of infectivity tests with plant viruses for compatibility with hypotheses. *J. gen. Microbiol.* **8**, 295.

A statistical method is described to test the compatibility between results of local-lesion counts and hypotheses relating changes in infectivity of plant-virus preparations to treatments applied to them. The method allows the variance-ratio test to be applied; it involves establishing a relation between numbers of lesions and virus concentration for each experiment and a logarithmic transformation of lesion counts to make variance independent of the magnitude of the variate. Its use is illustrated with results obtained to see whether inactivation of viruses by ultraviolet radiation is a first order reaction.

85. Last, F. T. (1953). Some effects of temperature and nitrogen supply on wheat powdery mildew. *Ann. appl. Biol.*, **40**. (In the press.)

The wheat variety Red Standard was more susceptible to infection by *Erysiphe graminis* at 14°–20°C. than at 7°C. Conidia were produced per unit area of pustule more than 10 times as rapidly at 14°C as at 7°C.

The increased susceptibility of wheat to mildew after applying nitrogenous fertilizer (N) was associated with changes in its growth rate. Both growth

rate and susceptibility increased to a maximum and then declined; the curves for the two were parallel with a lag of some days between effect on growth rate and effect on susceptibility. Plants which had passed through the susceptible phase and became resistant to mildew, again became susceptible when supplied with more N. Nitrogen-deficient plants continuously resisted infection.

The higher the average growth rate during an experiment the greater was the total amount of infection. Increasing the average growth rate was soon followed by a sharp increase in the amount of infection. When plants of two size groups received the same amount of N the initially smaller plants became more heavily infected than the larger plants.

86. (Nutman, F. J.) & Roberts, F. M. (1952). Acute die-back of clove trees in the Zanzibar Protectorate. *Ann. appl. Biol.*, **39**, 599.

The most widespread die-back of clove trees (*Eugenia aromatica*) in the Zanzibar Protectorate is caused by *Cryptosporella eugeniae* sp. nov. The most noticeable sympton is the death of a branch or a portion of a branch, or, in young saplings, of the entire tree ; in mature trees infection eventually leads to the semi-moribund trees now common in almost every clove plantation. The fungus invariably enters through a wound, most often one resulting from harvest damage. Pycnidia, and later perithecia, develop near the point of entry. Internally the infected wood is clearly distinguishable from the healthy by a dark red-brown stain.

Experimental infections that reproduce typical symptoms can rarely be caused in plants aged 18 to 36 months, and not at all in young seedlings. Experimental infection of older plants becomes more certain with increasing age, and with saplings of 7–10 years old failure is rare.

The prevalence of *Cryptosporella* die-back is almost entirely attributable to the destructive methods of harvesting now practised, combined with the presence of much infected material present in the plantations. Suggested control measures are based on the removal of old sources of infection and prevention of future damage, combined with remedial treatment where possible.

87. Watson, Marion A. & Healy, M. J. R. (1953). The spread of beet yellows and beet mosaic viruses in the sugar beet root crop. *Ann. appl. Biol.*, **40**, 38.

Multiple regression analysis of field data identified alate *Myzus persicae* as the most important factor affecting spread of beet yellows virus. Apterae of *M. persicae* and alatae and apterae of *Aphis fabae* were relatively unimportant.

A simple mathematical model of the spread of infection was developed. Assuming that the crop is visited by N aphids at a time when the proportion of plants infected is k_0, the predicted proportion of infection for a time 3–4 weeks later (k_1) is:—

$$k_1 = k_0 + 100\ (1 - k_0)\ (1 = e^{-NI})$$

where $I = p\ (\ (1 - k_0) + k_0\ t - 1)\ /k_0$

This formula adequately accounts for the observed spread when N = 1/10 sticky trap count for the 3–4 weeks preceding the time when k_0 infection is observed;

p = probability of infection by a single aphid = $\frac{1}{2}$

t = number of movements per aphid effective for spreading beet yellows virus = 5.

Once virus enters the root crops in spring, spread is mainly within fields, or between fields in the same neighbourhood. Where beet and mangold seed crops are common some plants in root crops become infected by summer migrants from seed crops. However, yellows is also more prevalent in seed-crop areas because the root crops in these areas are more heavily infested with *M. persicae*.

The proportion of plants infected by spring migrants entering the root crops before the end of June is small and variable. It is not significantly different in seed-crop and other areas. This implies either that initial virus comes equally from sources other than seed crops, or that, if the seed crops are the main sources, aphids that acquire virus from them during migration are later very widely dispersed.

In contrast to yellows, mosaic virus spreads mainly in the neighbourhood of seed crops within the seed-crop areas. No significant relation between aphid numbers and incidence of mosaic was established, but there is a strong suggestion that alatae of *M. persicae* and *A. fabae* spread the virus, and that both species contribute equally. This suggests that mosaic virus is not spread by aphids moving within the root crops, but only by infective migrants coming from outside sources. As the virus does not persist in the aphids, the sources must be near the root crops, and, as there is little spread within a crop, many infective migrants are needed to infect a large proportion of a crop. Seed crops often provide these conditions, as they contain infected plants, and both vector species breed on them. The irregularity of the data relating aphid numbers to mosaic incidence probably has two main causes; (1) differences in the incidence of mosaic in different seed crops, and (2) differences in the proportion of trapped aphids that have migrated from seed crops.

Nematology Department

General Papers

88. Fenwick, D. W. (1952). *Heterodera rostochiensis:* sampling techniques and the limits of their applicability. *Proc. Int. Nemat. Symp.* (1951), 8.

89. Franklin, M. T. (1952). Differentiation of species of *Heterodera*. *Proc. Int. Nemat. Symp.* (1951), 50.

90. Franklin, M. T. (1952). Some plant-parasitic Aphelenchs. Disease symptoms and hosts. *Proc. Int. Nemat. Symp.* (1951), 80.

91. Goodey, J. Basil (1952). The biology and host range of *Ditylenchus destructor*. *Proc. Int. Nemat. Symp.* (1951), 75.

92. Goodey, T. (1952). The present-day importance of *Pratylenchus* species. *Proc. Int. Nemat. Symp.* (1951), 84.

93. Peters, B. G. (1952). *Heterodera rostochiensis:* chemical control methods. *Proc. Int. Nemat. Symp.* (1951), 32.

94. Peters, B. G. (1952). The eelworm problem: biological aspects. Plant eelworms of the genus *Heterodera*. *Chem. & Ind.* (11th Oct.), 994.

95. Peters, B. G. (1952). Control of plant nematodes. *Rep. Progr. appl. Chem.*, **36**, 701.

Research Papers

96. Fenwick, D. W. (1952). The bio-assay of potato root diffusate. *Ann. appl. Biol.*, **39**, 457.

Experiments are described on the number of potato root eelworm larvae hatching in graded dilutions of potato root diffusate. In any sample hatching ability is proportional to the logarithm of its concentration and for each sample there is a " threshold " dilution beyond which it is inactive. Dilution curves for different diffusate samples are parallel. These relationships are utilized for standardizing any given sample.

97. Fenwick, D. W. & Reid, E. (1953). Seasonal fluctuations in the degree of hatching from cysts of the potato root eelworm. *Nature, Lond.*, **171**, Jan. 3, 17.

It is recorded that for the past three years hatching tests have been conducted throughout the year without any apparent diminution in the " hatchability " of cysts in winter time. The conditions of storage of cysts are described and it is concluded that the low hatches in winter months encountered by other workers result from the influence of the external environment.

98. Goodey, J. Basil (1952). Investigations into the host ranges of *Ditylenchus destructor* and *D. dipsaci*. *Ann. appl. Biol.*, **39**, 221.

Parasitism of (1) *Humulus lupulus*, (2) *Syringa vulgaris*, (3) *Tigridia pavonia*, (4) *Begonia tuberhybrida*, (5) *Gladiolus hybridus* and (6) *Tropaeolum*

polyphyllum which had been ascribed to *Ditylenchus dipsaci* was confirmed for (3), (4) and (5). *D. destructor* was found to attack all these except (4) and also to attack a new host, *Stachys palustris*.

99. Goodey, J. Basil (1952). *Tylenchorhynchus tessellatus* n.sp. (Nematoda: Tylenchida). *J. Helminth.*, **26**, 87.

100. Goodey, J. Basil (1952). *Rotylenchus coheni* n.sp. (Nematoda: Tylenchida) parasitic on the roots of *Hippeastrum* sp. *J. Helminth.*, **26**, 91.

101. Goodey, J. Basil. (1952). The influence of the host on the dimensions of the plant parastic nematode *Ditylenchus destructor*. *Ann. appl. Biol.*, **39**, 468.

Measurement data obtained from 11 populations of *D. destructor* indicate the significant effect of the host on the parasite. The essential importance of structural characters and the care with which measurements must be used, in the identification of a species, are emphasized.

102. Hesling, J. J. (1952). An improved method of separating eelworm cysts from debris. *J. Helminth.*, **26**, 69.

Hesling describes an adaptation of the entomologists' aspirator which has proved useful for picking up cysts of *Heterodera* species from the débris obtained when they are floated out of dried soil. The manipulation of the aspirator, and the part played by the apparatus in simplifying the estimation of *Heterodera* infestations in soils are fully explained.

103. Peters, B. G. (1952). Toxicity tests with vinegar eelworm. I. Counting and culturing. *J. Helminth.*, **26**, 97.

The vinegar eelworm is a useful laboratory animal which can be used in nematicidal work. Methods of culturing the worm in vinegar, 4 per cent sugar or 4 per cent ethanol solutions are described. Counts of worms in a 1 ml. counting slide are shown to conform with Poisson expectation. The negative geotropism of these worms is made use of by inducing them to climb from a dirty culture into clean medium: this also concentrates them.

104. Peters, B. G. (1952). Pot tests of nematicides against potato root eelworm. I. Pilot test and methods. *Ann. appl. Biol.*, **39**, 447.

Nematicides are applied to infested soil in glazed pots holding 20 lb. After some 4 weeks the soil is sampled to measure the eelworm kill, and a potato tuber is then planted in each. Height of haulms and weight of crop give evidence of phytotoxic or stimulating effects on the plants, and an end-of-season soil sample shows the extent to which the eelworm population has recovered from its initial set-back. Eelworm counts are handled in logarithmic transformation by analysis of variance, though probit analysis should also be practicable.

Insecticides and Fungicides Department

105. Glynne-Jones, G. D. (1952). The responses of the honey bee to repellent chemicals. *J. exp. Biol.*, **29**, 372.

1. This paper is concerned, first, with the development of a technique for maintaining a population of honey-bees (*Apis mellifera*) under conditions where it does not have access to naturally secreted nectar, but is allowed free flying conditions, and secondly with the application of this technique to the study of the chemotropic responses of bees to repellent chemicals.

2. Two types of stimuli are considered:

(*a*) The effect of the addition of the repellent to an attractant (sucrose solution).

(*b*) The effect of the repellent in the vapour phase in the vicinity of the attractant.

In (*a*) techniques are described for measuring the response with the standard attractant alternating in time and space.

3. Data collected on the rejection thresholds of acetic acid and phenol showed that whilst little variation in response occurred at the higher concentrations of the repellent, the offering of the standard attractant alternating

in time as opposed to space greatly modified the response. Tests were carried out to determine the reproducibility of the results.

4. It would appear that for a repellent chemical to be capable of effectively reducing the number of visits to a source of food, it must be capable of irritating the common chemical senses of the bee.

106. Glynne-Jones, G. D. & Edwards, R. A. (1952). Studies of toxicity of 3:5 dinitro-orthocresol and its sodium salt to the honey bee. *Bull. ent. Res.*, **43**, 67-78.

Laboratory and field experiments were carried out to study the toxicity of 3:5 dinitro-ortho-cresol and its sodium salt to the honey bee.

The acid DNOC was shown to be a rapidly acting poison under a wide variety of conditions and its toxicity was not greatly affected by differences in temperature or humidity during or after treatment.

Although both the acid and salt were equally toxic as stomach poisons, considerable differences were observed between the two substances as aqueous sprays and dry films. The toxicity of the sodium salt as an aqueous spray was considerably influenced by the humidity of the environment after spraying; the higher the humidity the greater the kill.

The sodium salt was apparently non-toxic as a dry film and increasing the humidity of the environment had no effect until the saturation point was reached and the salt went into solution. At this point the salt was almost as rapid in action as the acid. The type of surface on which the film was deposited was also shown to affect the toxicity.

Experiments were carried out on the penetration of the two substances through beeswax and these confirmed that whilst the acid could penetrate the beeswax in all forms tested, the salt would only penetrate in aqueous solution.

The effects of the acid DNOC on a population of foraging bees when used as a herbicide to control charlock in a 20-acre field of spring oats was investigated. It was shown that whilst the population of foraging bees was reduced no appreciable damage was inflicted on the colony. It is considered that at temperatures when active foraging on charlock takes place, spraying with DNOC will be followed by a rapid wilting of the flowers which will render them unattractive as sources of nectar or pollen.

107. Lord, K. A., Ward, J. (Cornelius, J. A. & Jarvis, M. W.) (1952). Chromatographic separation of the pyrethrins. *J. Sci. Fd. Agric.* No. 9, 419.

'Pyrethrins' I and II have been separated on both alumina and silica columns. On alumina columns there is some evidence of the separation of the cinerins from the pyrethrins.

Material separated in this way has been used to elucidate separations obtained by chromatography of pyrethrum extracts on paper impregnated with alumina and by paper chromatography of 2:4 dinitrophenyldrazine derivatives of the 'pyrethrins'.

108. Potter, C. (1952). An improved laboratory apparatus for applying direct sprays and surface films, with data on the electrostatic charge on atomised spray fluids. *Ann. appl. Biol.*, **39**, 1-28.

A description is given of the design and performance of a laboratory spraying apparatus which is an improved design on that described by the author in 1941. This apparatus is shown to be capable of giving a good replication and an even distribution over a circular area of 9 cm. in diameter with distilled water, a light petroleum oil and a heavy petroleum oil.

The effect of changes of temperature and humidity on the deposit are given. Some results are given of an investigation of the electrostatic charge produced on the droplets of distilled water and aqeuous solutions of wetting agents when these liquids are sprayed in the apparatus. The charge varied greatly with the solution, in the presence of two non-ionic surface active agents the charge was greatly increased over that with distilled water, while in the presence of an anionic material it was reduced so that it could not be measured with the available apparatus. There was however no correlation between the charge on the droplets and the amount deposited and this together with the evidence obtained by applying potentials up to 1·5 K.V.

on the spray target indicated that variations in electrostatic charge were not likely to cause variations in the amount deposited. It was concluded that the recorded variation in the amount deposited was probably due to variations in the amount of turbulence occurring in the spray tower. References are given to work illustrating the biological results obtained with the apparatus.

109. Potter, C. & Lord, K. A. (1952). The problem of the estimation of the insecticidal activity of pyrethrum by biological and chemical methods. *Pyrethrum Post.*, **3**, 12.

The problem of pyrethrum estimation has been reviewed and the merits of existing biological and chemical assay methods compared. It is concluded that none of the current methods of assay is entirely satisfactory, and that the present position would be improved if all the active constituents were isolated and separated in a pure unchanged state and their chemical, physical and biological activities examined both separately and in combination.

Entomology Department

110. Barnes, H. F. (1952). Plant Galls. *Bedfordshire Naturalist*, **6**, 24.

A popular account.

111. Barnes, H. F. (1952). Studies of Fluctuations in Insect Populations. XII. Further evidence of prolonged larval life in the wheat-blossom midges. *Ann. appl. Biol.*, **39**, 370.

The larvae of *Contarinia tritici* sometimes remains in the soil three winters before emerging as adult midges; the appearance of their parasites similarly is sometimes delayed two years. *Sitodiplosis mosellana* remains as larvae in the soil up to the twelfth summer after feeding in the wheat ears; in 1951 midges emerged from larvae that had been in the wheat in 1939, although some of these larvae had emerged as adult midges in all but two of the intervening years. Its parasites continue emerging for six years.

112. Barnes, H. F. (1952). Studies of Fluctuations in Insect Populations. XIII. An improved method of ascertaining the correct date to sample when assessing larval infestations of the wheat-blossom midges. *Ann. appl. Biol.*, **39**, 374.

Since the larvae only leave the ears during moist conditions, sudden diminutions in the infestations in the ears sometimes occurs after precipitation following a dry spell, thus leading to an erroneous assessment of the year's infestation. A method of taking small samples frequently during the period of larval growth allows any such errors in the main sampling to be rectified.

113. Johnson, C. G. (1952). A new approach to the problems of the spread of aphids and to insect trapping. *Nature, Lond.*, **170**, 147.

In view of the findings in the above mentioned work, it is now necessary to reconsider the epidemiological significance of research on aphid flight. Hitherto, most attention has been focussed on the problem of aphis migration and the conditions which control it. The significant approach now appears to be rather to study the reverse of this situation—namely the conditions which favour the *alighting* of aphids and the factors about the crops which encourage this.

114. Johnson, C. G. (1952). The changing numbers of *Aphis fabae Scop.*, flying at crop level, in relation to current weather and to the population on the crop. *Ann. appl. Biol.*, **39**, 525.

The current view that aphid migration is largely confined to calm weather and that this is controlled by the willingness or reluctance of aphids to take flight according to the strength of the wind can no longer be held. This paper shows that most migration occurs in windy weather (although the highest local *concentrations* are confined to calm periods), and that it is controlled mainly by population, not behaviour, changes.

115. Johnson, C. G. (1952). The bedbug. *New Biol.*, **13**, 80.

116. Johnson, C. G. (1953). The aerial dispersal of aphids. *Discovery*. **14**, 190

A popular account of the work in progress on aphid migration and especially the work on high altitude aerial drift.

117. Johnson, C. G. (1952). The infestation of beans by the Black Aphid *Aphis fabae* Scop. *J. R. agric. Soc.* **113**, 70.

An account of recent work on the rôle of weather in aphid migration and of the pattern of infestation of bean fields by the black bean aphid in relation to the prevailing wind direction.

118. Long, D. B. (1953). Some problems of polymorphism in insects. *Proc. R. ent. Soc., Lond.*, A. **27**, 99.

A review of literature illustrating some of the factors involved in polymorphism. The problem has been considered from the separate standpoints of the effect of the genetic constitution in producing variation and the effect of environmental factors which induce modifications as distinct responses.

119. Murphy, P. W. (1953). The biology of forest soils with special reference to the Mesofauna or Meiofauna. *J. Soil Sci.* (In the press.)

A review of the meso- and meio-fauna of forest soils from quantitative and qualitative points of view. The meio-fauna are broadly defined as those members of the Arachnida, Myriapoda and Insecta which are readily obtained by the funnel method of extraction. Details of the magnitude, nature and vertical distribution of the fauna of a Yorkshire heathland before and after afforestation are included. The pedological and biotic factors in the formation of mull and mor are considered. There is a discussion of the habits of soil fauna especially their role in the breakdown of tree litter; and the interplay of soil, tree species and fauna in the development of productive forests both for present and succeeding crops. The paper concludes with a brief appraisal of the influence of forestry practice in creating conditions which favour the development and maintenance of beneficial soil organisms.

120. Raw, F. (1951). The ecology of the Garden Chafer *Phyllopertha horticola* L. with preliminary observations in control measures. *Bull. ent. Res.*, **43**, 605.

An account is given of biological and ecological work carried out in S.W. England. *P. horticola* occurs naturally in poor quality permanent grassland on light soils. In some districts, e.g. North Wales, Dorset Downs, Lake District, it is a major pest.

The females lay about 14 eggs. Fecundity is correlated with weight which is related to larval food supply. Natural limitation of weight through competition for food among larvae may occur. Females will mate and lay fertile eggs without feeding and in general adult feeding does not affect fecundity. Over 90 per cent of eggs laid are fertile but fertility decreased with the age of the adult. The incubation period is about a month.

In the field eggs are laid in groups in the topsoil. The larvae gradually disperse but may regroup later at feeding sites. Larval mortality was highest where the turf was damaged. Population changes were related to adult dispersal, density of vegetation, consolidation, soil moisture and predators. Predation by birds can greatly reduce larval density.

Weeds are unaffected by infestation and damage is chiefly due to destruction of grasses. *Brachypodium pinnatum* is resistant because of its tough rootstock, *Dactylis glomerata* and *Lolium perenne* are relatively resistant, *Poa* spp. and *Festuca* spp. are readily damaged but regenerate when feeding stops or infestation declines. The distribution of *Poterium sanguisorba*, a favoured food plant may influence the distribution of *P. horticola*.

When infestation is severe and the grass roots are destroyed the soil aggregates are broken down. Soil structure is restored when the grasses regenerate and by consolidation.

Infestation was reduced by ploughing and reseeding. Dusting with 3·5 per cent B.H.C. at 70 lb. per acre during the flight period gave promising results when applied in favourable weather.

121. Williams, C. B. (1953). The international aspects of insect migration and insect drift. *Trans. 9th Int. ent. Congr.* **1**. 63.

A survey of our knowledge about the distances that insects travel, both by deliberate migration and by being blown by air currents, and a discussion of the importance of this in international problems of the spread of insects from one country to another, and the value of frontier inspections as a means of protection.

122. Williams, C. B. (1953). Graphical and statistical methods in the study of insect phenology. *Trans. 9th Int. Ent. Congr.* **2**,174

In the study of the dates of occurrence of biological events—such as the hatching of the eggs or the emergence of an adult insect—or the flowering of a plant or the arrival of a migrant bird—it is possible to compare results in different localities in the same year, or in the same locality in different years, and also at times a sequence of events in the same locality in the same year. There is also the interfering effect of the difference between different observers. Methods are discussed of laying out large numbers of records of this type in the form of diagrams to enable the basic facts to be easily seen. And also simple statistical methods for assessing the extent of the " errors " and hence the reliability of any conclusions.

123. Williams, C. B. (1953). The relative abundance of species in mixed animal populations. *J. Anim. Ecol.*, **21.** (In the press.)

A study was made of the frequency distributions of the abundance of different species in random samples of insects and birds taken from wild populations, and it is shown that while small samples tend to resemble the logarithmic series, when the samples are large (and so more likely to resemble the population sampled) the distribution is closer to the log-normal distribution than to the logarithmic series.

Bee Department

124. Abbott, C. P. & Butler, C. G. (1952). The scientist and the ciné camera. *Rep. Cent. Ass. Beekeep.*, Oct.

The use and value of the ciné camera as a tool in bee research, particularly with respect to investigations on bee behaviour, are discussed.

125. Bailey, L. (1952). The action of the proventriculus of the worker honeybee, *Apis mellifera*. L. *J. exp. Biol.*, **29,** 310.

A detailed account is given of the method of filtration of small particles (pollen grains and Nosema spores) by the proventriculus from the honey-stomach. The rates of filtration of different concentrations and sizes of particles, and of different volumes of suspensions, are analysed and the possible physiological significance of the filtration activity is discussed.

126. Butler, C. G. (1952). The development of British honeybees. *Rev. Ass. Agric., Lond.*, **17,** 9.

A discussion of the development of the strains of honeybees in Britain today, together with some views with regard to their future development.

127. Butler, C. G. (1952). Behaviour of social insects. *Nature, Lond.*, **170,** 642.

A synopsis of the papers on this subject read during the Belfast meeting of the British Association.

128. Butler, C. G. & Free, J. B. (1952). The behaviour of worker honeybees at the hive entrance. *Behaviour*, **4,** 262

Guard bees are not found at the hive entrance unless their colony has been alerted by the presence of robber bees or numbers of bees that have strayed from other colonies, or by disturbance of some kind. The degree of alertness exhibited varies under different conditions and with different strains of bees and may be of short or long duration. Intruders are not molested by unalerted colonies. Bees of various ages undertake guard duties and attempt to intercept and inspect other bees on the alighting-board of the hive. They recognise members of their own colony and distinguish them from bees from other colonies very quickly by scent. Robber bees are, however, recognised as such by their actions before the guards can approach and examine them.

On interception the fate of intruders is largely dependent upon their subsequent behaviour. The guards immediately try to sting robbers and will also fight violently with guard bees from other colonies, but very seldom attack other intruders. Many intruders adopt a submissive attitude and exhibit the ' displacement activity ' of tongue-stropping, sometimes passing into a state of thanatosis. A high proportion of submissive intruders are mauled and dragged away from the hive entrance irrespective of their age; however, those that do succeed in remaining in a strange colony for a few hours become accepted by the bees of that colony.

129. Hassanein, M. H. (1951). The influence of *Nosema apis* on the larval honeybee. *Ann. appl. Biol.*, **38**, 844.

It was found to be impossible to infect the larval honeybee with *Nosema apis*. In colonies suffering from this disease about 15 per cent of the eggs laid failed to result in adults, probably because of inadequate care and feeding.

130. (Kalmus, H.) & Ribbands, C. R. (1952). The origin of the odours by which honeybees recognise their companions. *Proc. roy. Soc. B.*, **140**, 50-59.

Bees from two colonies were trained to forage from different dishes, placed one yard apart. Their thoraces were distinctly marked. Recruits to the dishes were also distinctly marked, and they were found to be preferentially attracted to the dish visited by members of their own colony.

Recruits were not attracted to the dishes by the sight or sound of their companions. They were attracted by their distinctive odour. These odours were not inherited, but were produced by changes in the food supply of the colonies. They would develop between queenless halves of colonies.

Uniform and distinguishable colony odours are a consequence of the widespread food transmission which takes place amongst the foragers of each colony. Their rôle in orientation and the defence of the honeybee community is discussed.

131. Nixon, H. L. & Ribbands, C. R. (1952). Food transmission in the honeybee community. *Proc. roy. Soc. B.*, **140**, 43-50.

Six bees were trained to a dish, from which they collected 20 ml. of sugar syrup containing radioactive phosphorus. The distribution of radioactivity among the bees and larvae of their colony of 24,500 adults was then studied.

62 per cent of the foragers and 16–21 per cent of all the bees in the hive were radioactive within 4 hours. 76 per cent of the foragers and 43–60 per cent of all the bees were radioactive within 27 hours. The nurse bees were significantly less radioactive than the house bees and the foragers significantly more so. Within 48 hours all the large larvae in the unsealed cells were radioactive. The results are attributed to widespread food transmission.

It is suggested that food transmission is the foundation of the division of labour within the honeybee community, and of the similar odour produced by the members of each colony which serves for mutual recognition.

Food transmission would enable slow-acting insecticides contained in their food to be widely distributed among the members of a honeybee colony.

132. Ribbands, C. R. (1952). Division of labour in the honeybee community. *Proc. roy. Soc. B.*, **140**, 32-43.

Newly emerged bees in a colony were individually marked and their foraging activities were studied by subsequent observations at the hive entrance.

A few individuals gathered pollen throughout their foraging lives; many gathered none at all. Most gathered pollen at some time, but there was great diversity in the part of the foraging life at which this occurred.

There was considerable variation in the age at which different bees, emerging on the same day and living in the same colony, commenced foraging; this age ranged from 9–35 days. This variation was produced not only by alteration of the duration of the various hive duties, but also by omission of some of them. Such variation indicates that the division of labour is not determined by the age of the available workers, but is controlled by the requirements of the colony, the ages of the bees playing a subsidiary rôle.

The requirements of the colony are determined by its food supply, and they are appreciated by the individual as a consequence of widespread food transmission. Food transmission is, therefore, the most primitive and important method of communication in the honeybee colony.

133. Ribbands, C. R. (1952). The relation between the foraging range of honeybees and their honey production. *Bee World*, **33**, 2.

The gains in weight of groups of colonies sited on the edges of crops were compared with those of groups of colonies sited $\frac{3}{8}$ and $\frac{3}{4}$ mile away from the same crops. The experiments were repeated in two successive years. The effect of increased flying distance was large and detrimental, but its magnitude varied considerably. Most of the effect was due to weather conditions.

The results emphasize the importance of foraging range, and demonstrate how slight differences in apiary position or weather may cause the complete loss of a honey crop. They illustrate the advantages of moving colonies of bees to suitable crops and of using small apiaries.

134. RIBBANDS, C. R. (1952). The inability of honeybees to communicate colours. *Brit. J. anim. Behav.*, **1.** (In the press.)

Experiments determined that dancing foragers which can communicate the scent and whereabouts of a crop to other members of their colony, do not convey any information concerning the colour of the flowers of the crop.

135. RIBBANDS, C. R. (KALMUS, H.) & NIXON, H. L. (1952). New evidence of communication in the honeybee colony. *Nature, Lond.*, **170.,** 438. Reprinted in *Bee World*, **33.** (In the press.)

An article based upon the three papers summarized above and published in *Proc. roy. Soc. B.* **140,** 32.

136. SIMPSON, J. (1952). The composition of the stores produced by bees from sugar syrup. *Bee World*, **33,** 112.

The water content of stores derived from sucrose syrup was normal but the sucrose content was much higher than that of normal honey and was greater when the stores were produced from concentrated syrup than from dilute. The extent to which honey granulates is diminished by raising its sucrose content to that of stores derived from sucrose syrup. Although bees can effectively ingest *finely* granulated honey, granulation is in general undesirable, thus the presence of sucrose in syrup stores is probably beneficial.

137. WYKES, Gwenyth R. (1952). An investigation of the sugars present in the nectar of flowers of various species. *New Phytol.*, **51,** 210.

Quantitative determinations were made of nectar sugars by means of paper chromatography. In nectar obtained from 61 species sucrose, glucose and fructose were present in all but one sample. In addition, maltose and two other sugars of low RF values were found in the nectar of some species.

138. WYKES, Gwenyth R. (1952). The influence of variations in the supply of carbohydrate on the process of nectar secretion. *New Phytol.*, **51.** (In the press.)

The supply of carbohydrate available to nectar-secreting flowers was varied by different treatments and the influence of such variations on the amount and sugar concentration of nectar secreted was determined. Application of ringing and defoliating treatments to flowering shoots showed that the supply of carbohydrate may become a limiting factor for nectar secretion. In a series of sugar-feeding experiments it was found that the concentration of nectar and the amount of sugar secreted varied directly with the sugar concentration of the feeding solution, whereas the weight of nectar did not. Differences in the kinds of sugars supplied did not appear to influence nectar content.

139. WYKES, Gwenyth R. (1952). The preferences of honeybees for solutions of various sugars which occur in nectar. *J. exp. Biol.*, **29.** (In the press.)

When bees were offered equal volumes of sugar solutions, of different composition but the same total concentration, in laboratory and field experiments, it was found that sugars which occur in nectar were not equally attractive to them. Consistent preferences were shown for solutions of single sugars in the following descending order:—sucrose, glucose, maltose, fructose. The acceptances of some mixtures differed from those predicted on the basis of an additive effect of the constituent sugars in single solution. High preferences were shown for sucrose-glucose-fructose solutions.

No direct relationship appears to exist between the chemical constitution of the sugars offered and their acceptance by bees, and no adequate explanation can be offered for the observed differences in preferences for solutions of either single or mixed sugars.

The possible biological significance of such selective responses by bees is discussed.

Statistics Department

140. Boyd, D. A. *et al.* (1953). The Rothamsted experiments on field beans. Part I. Manuring and cultivation of field beans. *J. R. agric. Soc.*, **113**, 59.

This paper gives the results of experiments on the cultivation and manuring of beans carried out at Rothamsted in recent years together with some indication of the results obtained at other centres. The manurial experiments showed that a very good manuring for beans consists of ploughing in a moderate dressing of farmyard manure; where this is done it is unnecessary to apply fertilizer except on soils believed to be low in phosphate or potash. Where no farmyard manure is available the main need is for potash fertilizer while for phosphate it is difficult to justify any more than a very small dressing. Nevertheless in many counties a substantial proportion of farmers apply phosphate to beans whereas few of those not using farmyard manure apply potash. It is wasteful to use nitrogen on winter beans and it is of doubtful value for the spring crop.

Experiments comparing a PK fertilizer placed in bands near the seed compared with the same fertilizer broadcast showed that for both winter and spring beans placing a single dressing of fertilizer beside the seed gave yields as high as or higher than twice as much broadcast. For fertilizer sown in this way quite small dressings were adequate.

The main findings of the experiments on other husbandry factors are in favour of generous seed rates and early sowing; up to 3 cwt. seed per acre has proved to be profitable and sowing in early October has given better yields than sowing in late October or November. Increased seeding only partially compensates for late sowing. No difference was found between broadcast before ploughing and dropping the seed in the furrow by an attachment on the plough beam.

141. Church, B. M. (1952). Recent trends in fertilizer practice in England and Wales. Part I. The national position. *Emp. J. exp. Agric.*, **79**, 249. Part II. The use of fertilizers on cereals, root crops and grassland. *Emp. J. exp. Agric.*, **80**, 257.

Information is presented on the changes which took place between 1944 and 1950 in farmers' use of fertilizers. This data has largely been obtained from the results of fertilizer practice surveys carried out in eight districts in England and Wales in 1944–5 and in 1950. Estimates are made of the proportions of total fertilizer supplies used on different crops, and trends in the use of fertilizers on individual crops are examined. As far as the limited survey material allows, differences in the use of fertilizers in districts of different farming types are discussed. The times and methods of application of fertilizers to cereals in 1950 are examined and attention is drawn to the possibilities of increasing production by the more general use of fertilizers on cereals, fodder roots and grassland.

142. Grundy, P. M. (1952). The fitting of grouped truncated and grouped censored normal distributions. *Biometrika*, **39**, 252.

The fitting of a normal distribution, when all observations below some fixed value are wholly ignored ('truncated') or merely enumerated ('censored'), has been discussed by various authors. Fresh problems arise when the data are grouped, a situation relevant in entomological work. The present paper gives a solution of these problems, involving simple adjustments to the sample moments and to the estimated variances of the estimates.

143. Grundy, P. M. & Leech, F. B. (1953). A nomogram for assays arranged in randomized blocks. *Brit. J. Pharmacol.* (In the press.)

A scheme based on a nomogram has been devised for the routine computation of the 5 per cent fiducial limits of the relative potency of an assay arranged in randomized blocks. An illustration is given of the appropriate method of obtaining a range estimate of error.

The theory and construction of the nomogram are discussed; a table of the co-ordinates of the curves is provided to facilitate the construction.

Range is shown to be a reliable estimator of the error of tuberculin assays.

The magnitude of the interactions of "materials" and "slope" with blocks has been investigated. It is shown that in tuberculin assays they may be large and must therefore be eliminated from the estimate of error.

144. Healy, M. J. R. (1952). The analysis of lattice designs when a variety is missing. *Emp. J. exp. Agric.*, **20**, 220.

The intra-block analysis is given for simple, triple and balanced lattices with one variety missing. When the incomplete blocks have not been successful in eliminating soil variability, a randomized block analysis is recommended.

145. Healy, M. J. R. (1952). Some statistical aspects of anthropometry. *J. R. statist. Soc. B.*, **14**, 164.

This paper deals with some statistical problems arising in the treatment of anthropometric data on a large scale. Its aim is not so much to develop new statistical methods as to apply critically well-known regression techniques. The first part of the paper discusses the problem of collecting and recording the data in a way that will minimize the number of gross errors and will be well adapted to the subsequent computing processes. The rest of the paper exhibits three typical anthropometric problems and suggests appropriate methods of tackling them.

See also No. 87.

146. Hodnett, G. E. (1953). The responses of sugar cane to fertilizers in Trinidad. *Emp. J. exp. Agric.* (In the press.)

Using experimental results obtained within the past 20 years in Trinidad, mean standard responses of plant canes, first ratoons and second ratoons to nitrogen, phosphate, potash, pen-manure and by-products have been obtained. Responses to nitrogen have been associated with the moisture characteristics of the soils while those of phosphate and potash depend rather on the quantities of these nutrients available in the soils. In this series of experiments there were no great differences in response of plant canes and ratoons. The newer varieties showed rather greater responses than the old. Nitrogen and phosphate somewhat reduced the sugar percentage while potash increased it.

147. Hodnett, G. E. (1953). A uniformity trial on groundnuts. *J. agric. Sci.* (In the press.)

A uniformity trial on groundnuts has been analysed and the results discussed. Plant number is less variable than yield and less sensitive to shape of plots and of blocks. For yield, long narrow plots are more efficient than shorter wider plots, in all shapes and sizes of blocks and in Latin squares. The plots should not be arranged end to end along the contours, but side by side, either singly or in pairs, forming compact blocks.

The regression of the plot variance of the mean yield per unit area on size of plot approximately follows a linear logarithmic relationship. A similar relationship holds for plant number. The value of the regression coefficient b' is low and it has been shown that, as expected, there is considerable gain from the use of small blocks. The efficiencies of various confounded and incomplete block designs relative to designs in larger blocks have been determined for some particular layouts, and values for other layouts, ignoring shape of plots and of blocks, have been obtained by interpolation.

The field used for this uniformity trial appears equally variable in all directions.

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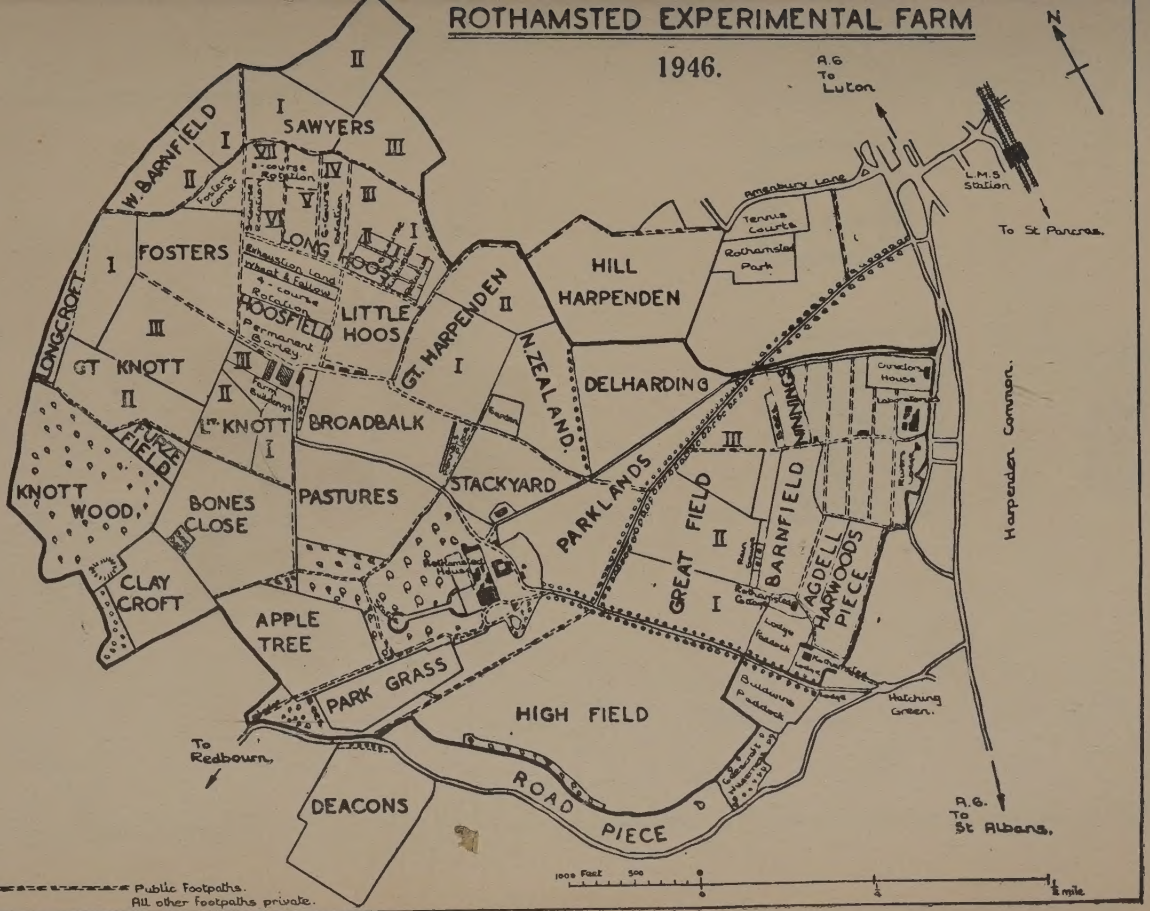
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¼
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